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Issued January 31, 1907.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 177.

A. C. TRUE, Director.

EVAPORATION LOSSES IN IRRIGATION AND WATER REQUIREMENTS OF CROPS.

BY

SAMUEL FORTIER,
Irrigation Engineer in Charge of Pacific District, Irrigation and Drainage Investigations.

(Work done in cooperation between the Office of Experiment Stations of the U. S. Department of Agriculture and the State of California.)

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*Bul. 58. Water Rights on the Missouri River and its Tributaries. By Elwood Mead. Pp. 80.

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[Continued on third page of cover.]

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1907.

THE OFFICE OF EXPERIMENT STATIONS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., November 1, 1906.

Sir: I have the honor to transmit herewith a report giving the results of experiments covering several years, made for the purpose of determining the amount of water lost by evaporation from irrigated soils, and the extent to which these losses can be avoided by improvements in methods of applying water and by subsequent cultivation of the soil. This work was done by the Irrigation and Drainage Investigations of this Office, in cooperation with the State of California, being carried on by Samuel Fortier, under the direction of Dr. Elwood Mead, chief of Irrigation and Drainage Investigations.

The report gives quantitative statements of the losses of water, and by calling attention to their magnitude should effect a saving of water now lost, and make possible a considerable extension of the irrigated areas where the water supply is limited.

It is recommended that this report be printed as a bulletin of this Office.

Respectfully,
A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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EVAPORATION LOSSES IN IRRIGATION.

INTRODUCTION.

Investigations have been carried on for a number of years by the Office of Experiment Stations of the United States Department of Agriculture for the purpose of determining the extent of the chief losses to which irrigation water is subjected. These studies have embraced the evaporation, percolation, and leakage losses from earthen channels, and the loss of water caused by faulty and crude methods of distribution, by unskilful application, and by negligence in not properly preparing the land to receive water. The data already collected point to the conclusion that at least one-half of the water which is taken from natural streams is lost in one or more of the ways named. This, however, does not include the water evaporated from cultivated and cropt fields, for the reason that there was no reliable information on which to base conclusions. The purpose of the experiments herein reported was to determine not only the evaporation losses but remedies which would lessen these losses.

These investigations have formed part of the cooperative work in irrigation which has been carried on for several years by the Office of Experiment Stations and the State of California. While they have been undertaken chiefly for the benefit of irrigators in California, it is hoped the results will prove of benefit to others in bringing about a more economical use of water and at the same time increasing the value of soil products.

The writer also hopes that the results will shed additional light on the subject of extending irrigation in the semiarid portion of the West, where the water supply is limited in volume and where agriculture is likely to be a combination of a small area irrigated with a larger area cultivated without irrigation. Here the conservation of moisture, whether supplied by rainfall or by irrigation, is the fundamental agricultural necessity.

The writer gratefully acknowledges his indebtedness for valuable assistance in conducting the experiments to the following persons: During the latter part of 1903 and the summer months of 1904, much of the field work was in charge of Arthur P. Stover, irrigation engineer; J. E. Roadhouse, instructor in irrigation in the Polytechnic School of San Luis Obispo, Cal., was in charge of the field experiments in irrigation at Riverside during June and July, 1905, and was succeeded by O. W. Bryant, and Frank Adams, irrigation engineer, has not only taken charge of a part of the crops grown in tanks, but has also assisted in the compilation of the data and the preparation of parts of this report.

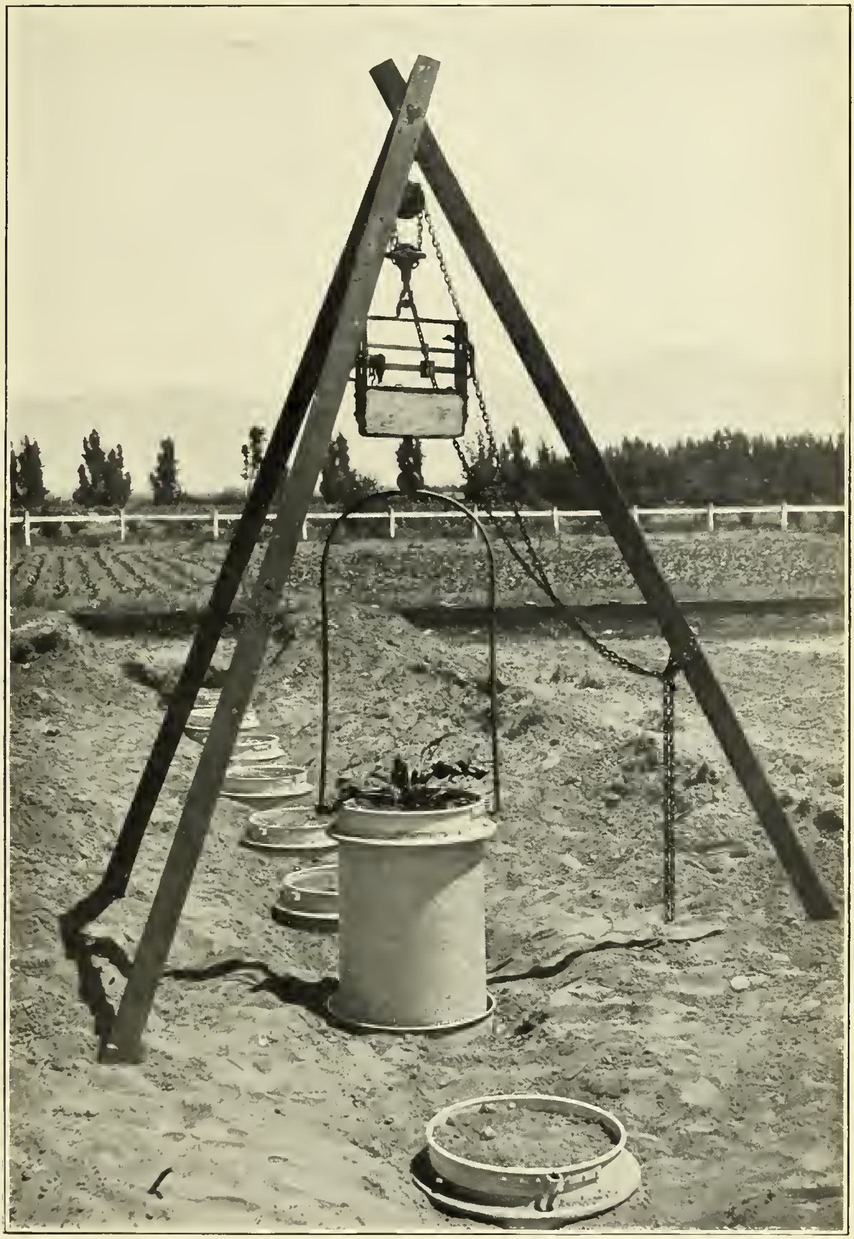
SITES AND EQUIPMENT.

In conducting experiments on evaporation losses in irrigation the chief difficulty is in securing natural conditions. Laboratory tests are easily made, but the evaporation from soils in the artificial surroundings of a laboratory is likely to be quite different from that from similar soils in the open field. On this account it was decided, when the work was first planned in 1903, to conduct all experiments in the open field.

An important consideration in the selection of sites was to secure the services of reliable men for short periods each day who would make and record the necessary observations. It was largely on this account that an equipment was purchased and installed at the substation of the University of California, located near Tulare, Cal., and another at the substation near Pomona, Cal. The former was in charge of Julius Forrer, and the latter during 1903 was in charge of J. W. Mills, who was succeded by J. H. Barber. Berkeley was selected as one of the stations at which evaporation experiments were to be made on account of its nearness to the California office of Irrigation and Drainage Investigations of the Office of Experiment Stations. The station in the Sacramento Valley was located first at the Forestry substation, but was subsequently removed to the plant-introduction garden of the Bureau of Plant Industry, near Chico. In the spring of 1905, the Arlington Heights Fruit Company, of Riverside, Cal., which owns about 2,000 acres in bearing citrus trees, offered to set aside block 58, containing 10 acres, for experiments in irrigation. Their offer was accepted, and it was on this site that the tank experiments at Riverside were carried on. The same company also provided temporary offices, a laboratory, and other equipment free of charge.

The plan followed in determining the rate and amount of evaporation from soil surface was to remove from a field 300 to 1,300 pounds of soil, place it in a vessel as nearly as practicable in its natural position, and by periodical weighings ascertain the loss of moisture from the soil.

In seeking to secure natural conditions for the earth which was placed within the tanks, typical soil and free exposure to sunshine, wind, and rain were easily obtained, but it was more difficult to maintain in the soil within the tanks the same temperature as that in adjacent soil.



APPARATUS FOR LIFTING AND WEIGHING TANKS.

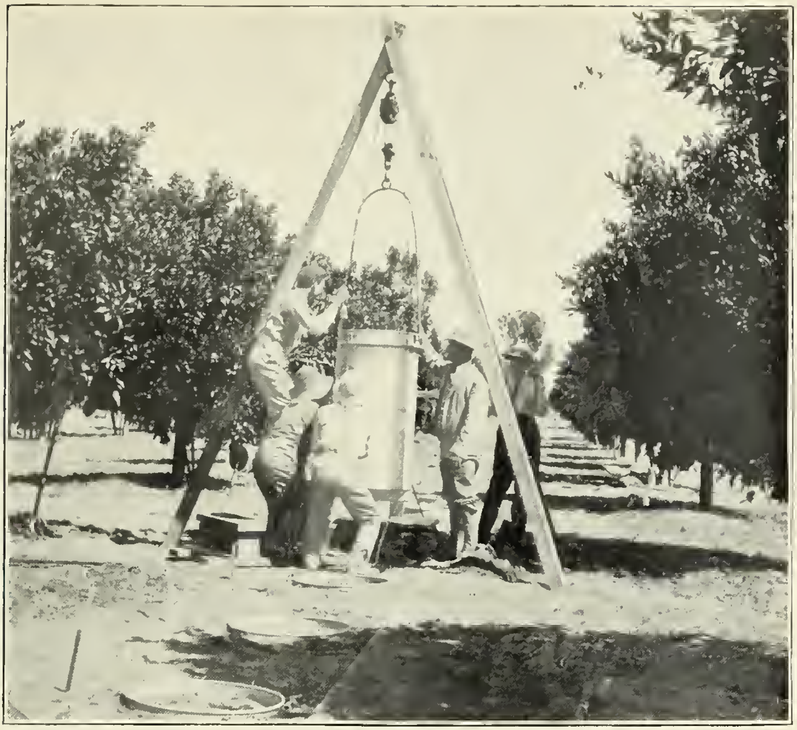


FIG. 1.—TANKS AND APPARATUS FOR WEIGHING.

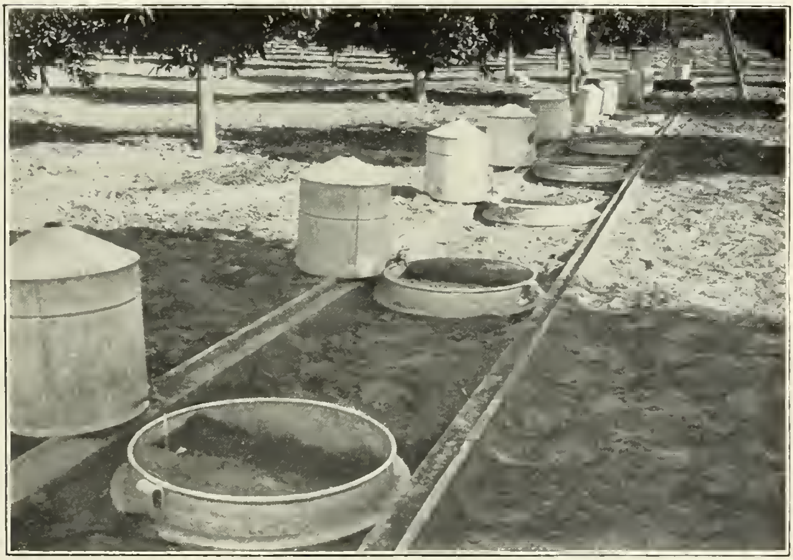


FIG. 2.—METHOD OF APPLYING WATER TO TANKS.

While experimenting along this line in Utah and Montana the writer first used single tanks sunk into the ground to the level of the surface and afterwards the same kind of a vessel placed inside a larger but shorter vessel which contained water. In the first the temperature of the soil was too high and the second was inconvenient to weigh. The smaller tanks used in the California work are shown in Plate I and were designed by A. P. Stover. The outer tank is a plain cylindrical vessel made of galvanized iron, about 19 inches in diameter and 30 inches long. It was placed in the ground on a level with the surface and moist earth tamped around it. The spacing between these outer tanks was usually 4 feet. On the inner-tank, which was 17 inches in diameter and 30 inches long, a flange was riveted some 2½ inches from the top. When the outer tank was party filled with water and the inner tank placed within it, the flange of the latter rested on the top of the former. Water could be poured into the annular space thru a half-inch hole made in each flange.

The chief advantage in using double water-jacketed tanks was in lowering the temperature of the soil in the tanks. The results of numerous observations showed that the temperature of the water which was confined in the space between the outer and inner vessels was practically the same as that of the adjacent soil which had not been disturbed. The ease with which a tank could be raised, weighed, and lowered was another advantage of water-jacketed tanks. Two lugs were riveted to each of the inner tanks, in which a bale was inserted. A scale was placed above, and the whole raised by means of a derrick and a differential pulley block (Pl. I).

The water-jacketed tanks designed later by the writer for the Riverside experiments were of the following dimensions: Inner 23½ by 47 inches and outer 26 by 47 inches. The weights were determined by placing the tanks on a platform scale resting on a wooden track. The location of these tanks in the orchard, the platform scale, wooden track, and derrick are shown in Plate II, figure 1.

INFLUENCE OF CULTIVATION AFTER IRRIGATION.

The belief that soil should be cultivated after it is irrigated is quite general among western farmers and orchardists, but is not very generally put in practise. This applies to orchards and vineyards and to all crops that require cultivation at intervals. By cultivation the condition of the soil is improved and the available moisture conserved, and the main purpose of the experiments to be described was to determine how much water is lost by neglecting to cultivate after each irrigation. It was arranged so as to bring out two points: (1) The amount of water evaporated from the surface of soil from the time water is first applied until it is fit to cultivate, and (2) the losses by evaporation from cultivated and uncultivated soils which have been previously irrigated.

FIRST EXPERIMENT.

The site selected for the experiment was the southwest corner of block 58, Arlington Heights Fruit Company, located on Arlington Heights, about 6 miles from the city of Riverside, Cal. Eight water-jacketed tanks were used, the inner tank of each set being 23½ inches in diameter and 47 inches deep. This held from 1,000 to 1,200 pounds of soil. A trench 30 inches wide was dug midway between two rows of orange trees, and in this the tanks were placed 4 feet apart. The top of the outer tank was slightly below and that of the inner slightly above the natural surface of the ground. Water of the same temperature as the adjacent earth was then poured into the outer tanks. The soil used to fill the tanks was taken from block 58 and is thus described by Dr. R. H. Loughridge, of the University of California:

> The soil is a sandy loam of good texture, more or less micaceous and granitic in origin, being derived from the hills on the south, in which are great masses of granite composed of quartz, orthoclase feldspar, and biotite or black mica. The soil is, thruout the tract, underlaid by a highly micaceous and more or less gritty loam at depths varying from 2 to 5 feet, as was shown by the preliminary examination. The grit consisted of small fragments, partly granitic, with its minerals still intact, and of single grains of feldspar and quartz loosened from the rock by weathering agencies. It is irregularly distributed, sometimes in pockets or small bodies of little else than grit inclosed in the loam, sometimes occurring sparingly in the loam. Occasional pieces the size of gravel of either granite, quartz, or feldspar were met with in the examination. Still deeper down this mixt loam and grit is underlaid by a bed of almost pure grit of the same character, and reaching in places many feet in thickness.

Care was taken to have the different layers of soil occupy the same relative position within the tanks that they had in the orchard, and the proper degree of compactness was obtained by lightly tamping each 2-inch layer. Four samples of soil taken from each tank showed that there was no free water in the top foot and that it varied from 5 to 7 per cent thruout the balance of the soil.

In applying the water after the initial weights had been taken, the intention was to imitate orchard practise by making a furrow 4 inches deep across the top of each tank and permitting the usual amount of water to trickle into it from the faucet of a 10-gallon oil can, as is shown in Plate II, figure 2. In gaging the faucets too much water was allowed to pass, and in ten hours 15 gallons of water had been absorbed by the earth in each tank. The plan was not to use more than this in forty-eight hours, and in order to keep the furrows moist more water was added. Each tank received 172 to 202 pounds of water, which corresponded to depths over the surface of 11 to 13 inches. The tanks were weighed for the first time July 13, and afterwards on July 14, 15, 17, and 18 and the evaporation losses for each period computed. On July 14, or twenty-four hours after the first water had been supplied, the soil was saturated, but on July 18 it was found to be sufficiently dry to be cultivated, and on that date, or five days after the beginning of the experiment, the soil in alternate tanks was cultivated to a depth of 6 inches. The weighings were then continued on July 20, 21, 22, and 24, or for a period of six days, making eleven days in all. The results were as follows:

Evaporation losses from bare soils near Riverside, Cal., for the first five days after irrigation.

No. of tank.	Initial weight of tank and soil.	Water added.	Evaporation losses.						
			First day.	Second day.	Third and fourth days.	Fifth day.	Total in five days.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
1	1,054.00	202.50	11.25	5.75	9.00	2.75	28.75	1.83	14.2
2	1,028.00	188.50	11.25	3.75	8.50	3.25	26.75	1.70	14.2
3	1,047.00	196.00	12.75	6.25	9.25	3.25	31.50	2.01	16.1
4	1,043.25	177.25	11.25	5.75	10.25	3.00	30.25	1.93	17.1
5	1,056.00	192.00	6.75	5.75	7.50	3.75	23.75	1.51	12.4
6	1,000.25	171.80	11.50	3.50	8.50	4.50	28.00	1.78	16.3
7	1,064.50	178.25	9.25	3.50	9.50	3.75	26.00	1.66	14.6
8	1,016.50	176.00	10.50	4.50	8.00	3.50	26.50	1.69	15.1

Evaporation from bare soils near Riverside, Cal., from the sixth to the eleventh day after irrigation on both cultivated and uncultivated soils.

SOIL CULTIVATED 6 INCHES DEEP.

No. of tank.	Initial weight of tank and soil.	Water added.	Evaporation losses.						
			Sixth and seventh days.	Eighth day.	Ninth day.	Tenth and eleventh days.	Total in six days.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
2	1,028.00	188.50	6.00	2.00	0.50	2.00	10.50	0.67	5.6
4	1,043.25	177.25	5.00	1.25	1.25	2.50	10.00	.64	5.6
6	1,000.25	171.80	4.25	1.75	1.25	1.50	8.75	.56	5.1
8	1,016.50	176.00	5.75	2.00	1.25	2.00	11.00	.70	6.3

SOIL NOT CULTIVATED.

No. of tank.	Initial weight of tank and soil.	Water added.	Sixth and seventh days.	Eighth day.	Ninth day.	Tenth and eleventh days.	Total in six days.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
1	1,054.00	202.50	6.50	3.25	3.50	10,00	23.25	1.48	11.4
3	1,047.00	195.00	7.25	2.25	3.75	8.75	22.00	1.40	11.3
5	1,056.00	192.00	10.75	2.50	2.00	6.25	21.50	1.37	11.2
7	1,064.50	178.25	7.25	2.75	3.00	7.25	20.25	1.29	11.3

The losses in each pair of tanks were nearly equal for the first five days, or until after the top soil in one-half the number was cultivated, but after July 18 and up to the end of the experiment on July 24 the loss of soil moisture in the uncultivated tanks was much greater than in the cultivated tanks. In more general terms, the dry, sandy loam of an orchard was heavily irrigated by the furrow method and in five days of summer weather, in which the thermometer during the day averaged 81.2°, the average loss by evaporation from eight tests was 15 per cent of the amount applied. After this date the soil in one-half the tanks was untouched. Of the amount of moisture supplied by irrigation an average of 5.7 per cent was lost in six days from the cultivated tanks, and an average of 11.3 per cent from the uncultivated tanks. The same results are shown graphically in figure 1, in which tons per acre are substituted for pounds per tank.

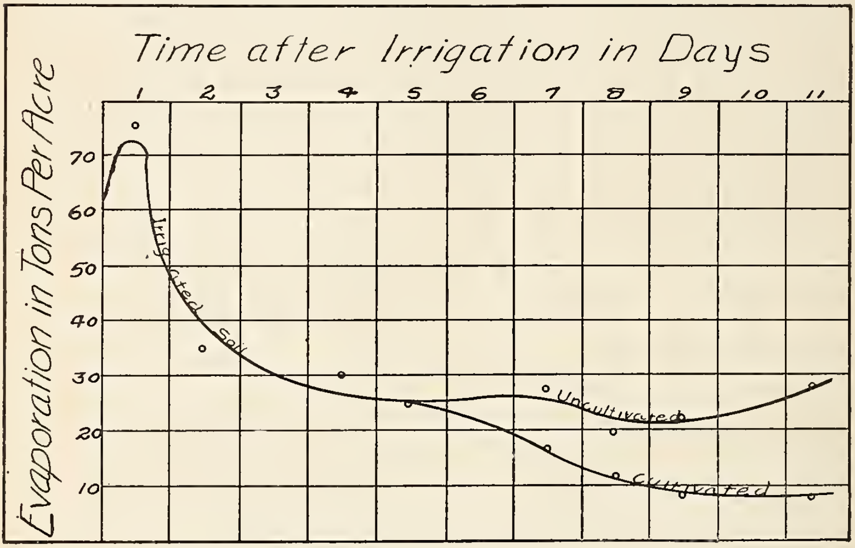


Fig. 1.—Diagram showing the saving of water resulting from cultivation.

That these results may be more readily applied to other portions of arid America, a fairly complete set of temperature observations was taken morning, noon, and evening, a summary of which is contained in the table following. The temperature of the water refers to the surface of the water in the evaporation tanks and the shaded soil refers to those portions of the surface which were shaded by orange trees.

Temperature near Riverside, Cal., July 11–24, 1905.

Date.	Air in shade.	Soil.		Water.	Moist soil.	Remarks.
		In shade.	In sun.			
July 11:	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	
12 m	82	79	129	86	....	Cool breeze.
5 p. m.	79	87	103½	81	....	Do.
July 12:						
8.30 a. m	65	70½	73½	75	....	Misty; fog.
12 m	80	78	125	84½	95	
5 p. m	78	84	96	79	73	Cool breeze.
July 13:						
8.30 a. m	63½	70	71	73	....	Foggy.
12 m	78	79½	121	80	89	
5 p. m	81	77	94	78½	76½	
July 14:						
8.30 a. m	67½	72½	76	73¼	....	Do.
1 p. m	77½	78½	102	78	80	Fog clouds.
5 p. m	75½	75½	94	75	75½	
July 15:						
8.30 a. m	77½	77	99½	74½	79	Clear.
12 m	83	82	130	86	89	
5 p. m	82½	91	107	78	75½	

Temperature near Riverside, Cal., July 11–24, 1905—Continued.

Date.	Air in shade.	Soil.		Water.	Moist soil.	Remarks.
		In shade.	In sun.			
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	
July 16						
July 17:						
8.30 a. m	61	65	65½	72	67	
12 m	77½	73½	122	82	92	
5 p. m	80½	80	96	78	78	Breeze.
July 18:						
8.30 a. m	63	67	72	71	68	High fog.
12 m	75½	75	122	82½	96½	
5 p. m	80	80	102	78	74	
July 19:						
8.30 a. m	63	67	67	71	69	Misty.
12 m	83	77	126	83	95½	
5 p. m	83½	84	104	79½	74½	
July 20:						
8.30 a. m	66	71	76	71¾	72	High fog.
1.30 p. m	90	85	136	87½	103	
5 p. m	90½	90	110	82		
July 21:						
8.30 a. m	63	67	68	71	69	Misty.
12 m	96	78	102	84	96	Breeze.
5 p. m	86	85	92	78	82	
July 22:						
8.30 a. m	74	73	88	75	72	Clear.
12 m	94	89	138	88	97	Breeze.
5 p. m	88	93	100	78	85	Do.
July 23:						
8.30 a. m	78	71	86	74	79	Clear.
12 m	94	87	126	80	86	
5 p. m	90	97	100	78	76	
July 24:						
8.30 a. m	75	70	82	73	67	Do.
12 m	96	89	109	82	90	
5 p. m	90	89½	108	81	79	Do.

SECOND EXPERIMENT.

Owing to the large amount of water which was applied in the first experiment it was decided to repeat the experiment, but to use less water. Accordingly, on September 23, 1905, the same eight tanks were filled with similar soil, the free-moisture content of which averaged 3.11 per cent. From 3 to 4 inches of dry soil mulch was placed on the surface of each and the water applied as in the previous experiment to a 4-inch furrow from the faucet of a 10-gallon can, each tank receiving 125.25 pounds. The water ran continuously from 3 p. m. September 23 to 5 p. m. September 24, and from 9 a. m. to 3.30 p. m. September 25. On the morning of September 24 all the surface soil in each tank was moist. It dried out to some extent during the day, but was again moist the next morning. During the afternoon of September 26 the tanks were weighed a second time and the losses during the three-day interval ascertained. Immediately after weighing, alternate tanks were leveled and cultivated to a depth of 6 inches. The tanks were weighed for the third and last time on September 29.

The condition of the weather while this experiment was being made was similar to that during the former experiment, but in order that a comparison may be made of the various temperatures, the following table is inserted.

Temperatures near Riverside, Cal., September 24–29, 1905.

Date.	Air.		Soil.		Water (sun).	Moist soil.	Remarks.
	In shade.	In sun.	In shade.	In sun.			
September 24:	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	
8 a. m.	73½	79½	68½	89	71	79	Clear.
1 p. m.	94	100½	93	136	86½	93	Clear; light breeze.
5 p. m.	82	82½	83½	90	76	75	Clear.
September 25:							
8 a. m.	72	77½	65	87	70	64	Do.
1 p. m.	93½	99	92	130	85	88	Do.
5 p. m.	82	83	83	90½	75½	74	Do.
September 26:							
8 a. m.	71	78½	64	86	69½	65	Do.
1 p. m.	97	100½	93	130	88	85½	Clear; light breeze.
5 p. m.	83	84	84	92	85	83	Clear.
September 27:							
8 a. m.	66	77	62	80	68½	68½	Do.
1.15 p. m.	89	92½	87	116	81½	88½	Clear; light breeze.
5.20 p. m.	71½	73	81	82	73	72½	Clear.
September 28:							
8 a. m.	62½	65½	68	78½	69½	66	High fog.
1 p. m.	75	84	84	98	73½	78½	Cloudy.
5 p. m.	66	67	73	75½	72½	65	Very cloudy.
September 29:							
8 a. m.	59½	67½	54½	76½	64½	55½	Clear.
1 p. m.	....	....	....	....	....	....	
5 p. m.	....	....	....	....	....	....	

At 8 a. m. water tanks were always in the shade; at 1 and 5 p. m., in the sun.

In the accompanying tables are given the results of the various weighings and the corresponding losses:

Evaporation losses from bare soils near Riverside, Cal., for the first three days after irrigation.

Number of tank.	Initial weight of tank and soil.	Water added.	Evaporation losses.	
	Pounds.	*Pounds.*	*Pounds.*	*Per cent.*
1	1,060.00	125.25	15.25	12.2
3	1,056.75	125.25	14.50	11.6
5	1,058.25	125.25	11.50	9.2
7	1,066.25	125.25	12.25	9.8
2	1,063.75	125.25	15.00	12.0
4	1,029.50	125.25	10.75	8.6
6	1,051.00	125.25	12.25	9.8
8	1,058.25	125.25	13.25	10.6

Evaporation losses from bare soils near Riverside, Cal., from the fourth to the sixth day after irrigation, on both cultivated and uncultivated soils.

SOIL CULTIVATED 6 INCHES DEEP.

Number of tank.	Initial weight of tank and soil.	Water added.	Evaporation losses.	
	Pounds.	*Pounds.*	*Pounds.*	*Per cent.*
2	1,063.75	125.25	1.00	0.8
4	1,029.50	125.25	1.75	1.4
6	1,051.00	125.25	1.50	1.2
8	1,058.25	125.25	1.75	1.4
SOIL NOT CULTIVATED.				
1	1,060.00	125.25	3.00	2.4
3	1,056.75	125.25	5.25	4.2
5	1,058.25	125.25	5.00	4.0
7	1,066.25	125.25	4.50	3.6

While the rate of evaporation is somewhat less than when a larger amount of water was applied, the value of cultivation in checking evaporation is again clearly indicated. Of the 8 inches which were applied to the tanks an average of 10.5 per cent was evaporated the first three days after irrigation, while in the three days following cultivation the average loss from the cultivated tanks was 1.2 per cent, and that from the uncultivated tanks 3.6 per cent—three times that from the cultivated tanks.

Both experiments show that the losses are much heavier immediately after irrigation than at any later time, and that they decrease quite rapidly from day to day. In both instances the losses from the cultivated tanks were less than half those from the uncultivated tanks, showing the advantage of cultivating as soon as possible after irrigation.

INFLUENCES OF SOIL MULCHES IN CHECKING EVAPORATION.

In the citrus orchards of southern California the depth of soil mulches varies all the way from 2 to 10 inches. The usual practise a decade or more ago was to cultivate the top layer of soil 2 to 4 inches deep, but the introduction, during late years, of deeper irrigation has been followed by a corresponding increase in the depth of cultivation. Comparatively few orchardists now cultivate less than 6 inches, and many of the more progressive lower their cultivators to depths of 9 to 10 inches.

Before proceeding to discuss the influence of soil mulches, and particularly of deep-soil mulches, in checking evaporation, it may not be amiss to outline, briefly, some of the additional advantages of such mulches in orchard culture, and more particularly in citrus culture.

In the first place, deep mulches tend to absorb the rainfall of winter and lessen the run-off from cultivated orchards. Altho the rainfall in the southern and central portions of California is light, yet heavy precipitations for short periods are common. Last year at Pomona, Cal., the rainfall from March 11 to March 30, inclusive, a period of nineteen days, amounted to 7.21 inches. When so much water falls in so short a time on soil that is cultivated only a few inches deep, a large part is liable to flow into the nearest stream and be wasted. This is more likely to happen if there is a hard layer of soil beneath the shallow mulch.

Again, in cultivated soils which contain much alkali one frequently notices a crust of that material covering the surface. Natural forces have raised the moisture in the soil to the surface, the pure water has past into the air, and the impurities have remained. This process is particularly active in soils which are not properly cultivated, or shaded with a growing crop, and likewise in soils which have little or no soil mulch. Now, the same natural forces which bring up the injurious salts and deposit them at or near the surface also bring up the useful salts, such as nitrates, the sulfates, and the phosphates. These valuable ingredients are removed from that portion of the soil which contains the roots of citrus trees and are deposited in the top layer, where there are no roots. It has been repeatedly shown, however, that these natural forces can act but feebly, if at all, thru a deep-soil mulch, and this demonstrates the value of a covering of this kind in preventing the rise not only of the injurious salts, such as alkali, but likewise of the valuable salts, such as nitrates.

Deep cultivation and deep mulches also prevent the accumulation of roots in the surface layer. The orange is said to be a shallow-rooted tree in its natural state, and the tendency of the roots is to spread out near the surface. The tree is encouraged to do this during the rainy season, when the surface is kept moist by frequent rains and when the evaporation is reduced to a minimum by cool weather, fogs, and rain. Yet it is doubtful if the roots found in the upper 6 inches of soil benefit the tree. While these may collect both food and moisture during the three months of a rainy season, the excessive evaporation during a thirty-day or forty-five-day period between irrigations in summer is pretty certain to wither and kill the fibrous rootlets. On this account it is deemed better to prevent the extension of roots thru the top layer of soil by frequent deep cultivations.

Deep cultivation and deep mulches not only tend to prevent the formation of hardpan, but do much to break one already formed. In some orchards the long-continued and shallow cultivation of the soil to the same depth, coupled with shallow irrigation, creates a compact layer beneath thru which water does not readily percolate. This layer can, however, be broken up by deeper cultivation, in which the depth is varied from year to year, and by permitting water to flow for several days in deep furrows.

Lastly, soil mulches of all kinds, whether deep or shallow, by pulverizing the soil enable the air to circulate thru the mass and thus convey a supply of oxygen to the roots of plants, as well as to all those minor organisms which assist plants in their proper development.

Notwithstanding the advantages of soil mulches, and particularly of deep mulches, that have just been mentioned, the fact remains that the main purpose of all soil mulches is to lessen the amount of evaporation from the surface of cultivated soils.

The purpose of the experiment was to ascertain (1) the difference between the amount of water evaporated from an orchard soil which contained no mulch and one which was covered with a mulch of a given depth, and (2) to compare the effects of mulches of different depths in reducing the loss of water by evaporation. In this experiment 14 water-jacketed tanks were used. The inner tanks of Nos. 1 to 8, inclusive, were 23½ inches in diameter and 47 inches deep, and the inner tanks of Nos. 10 to 12, inclusive, were 17 inches in diameter and 30 inches deep. These 11 tanks were filled with soil previously described taken from block 58, of the Arlington Heights Fruit Company, put in position, and divided into the following groups:

First group, Nos. 1 and 3, no mulch.
Second group, Nos. 2, 4, and 10, 4-inch mulch.
Third group, Nos. 5, 7, and 11, 8-inch mulch.
Fourth group, Nos. 6, 8, 12, and 14, 10-inch mulch.

The state of the weather, as indicated by the temperature, during the greater part of the time of the experiment is given in the following table:

Temperature at Arlington Heights, Riverside, Cal., June 30 to July 8, 1905.

Date.	Air in shade.	Water.	Soil.		Remarks.
			In sun.	In shade.	
	°*F.*	°*F.*	°*F.*	°*F.*	
June 30:					
8.30 a. m	64	71	81	75	Foggy.
12 m	68	82	130	81½	
5 p. m	83½	78	103	86	
July 1:					
8.30 a. m	64	72	78½	75½	Do.
12 m	88	82	135	81	
5 p. m	88	78½	109½	82½	Gentle breeze.
July 2:					
8.30 a. m	77½	76	99½	71½	Clear.
12 m	97	99	141	86½	
5 p. m	93	80½	111	94	Warm breeze.
July 3:					
8.30 a. m	82	76½	106	75½	Clear.
12 m	100	88	145	95½	
5 p. m	93	81	105	92	
July 4:					
8.30 a. m	87	80	104	78	Do.
12 m	106	88	147	99	
5 p. m	96	82	114½	98	
July 5:					
8.30 a. m	87	80	115	78½	Do.
12 m	102	89	148	94½	Hot breeze, 3 to 5 p. m.
5 p. m	98½	81½	124½	97	
July 6:					
8.30 a. m	90½	81	116	78	
12 m	104½	89	150	94½	Hot breeze.
5 p. m	97½	93	118	97	Hot wind, 1 to 4.
July 7:					
8.30 a. m	89½	80½	114	80	Hot wind.
12 m	106	90	140	105½	
5 p. m	97	82	120	95½	All day.
July 8:					
8.30 a. m	86½	80	112	79	Clear.
12 m	98	86	139½	91	Breeze.
5 p. m	90	80½	112	98	

On June 24, 49.25 pounds of water were applied to each of the large tanks and 24.62 pounds to each of the small tanks. In the first group the water was applied on the surface of the soil, while in the remaining groups the mulch was not put on until after the water was applied. When the soil in the tanks had absorbed the water a dry-soil mulch of the required thickness was spread over the top and the initial weights of the tanks ascertained. All tanks were weighed five times during the experiment, which lasted fourteen days, with the results as given in the following table:

Evaporation from soils protected by soil mulches of different depths, June 24 to July 8, inclusive, 1905.

Condition.	Tank No.	Initial weight.	Water added.	Losses.						
				June 24-27.	June 27-July 1.	July 1-5.	July 5-8.	Total.		
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inch.*	*Percent.*
Surface	1	1,123.0	49.3	6.5	3.0	1.0	0.5	11.0	0.70	22.3
	3	1,123.5	49.3	7.0	3.0	1.5	.0	11.5	.73	23.3
4-inch mulch	2	1,155.5	49.3	1.5	.25	.5	.25	2.5	.16	5.1
	4	1,135.0	49.3	2.5	1.0	.5	.0	4.0	.26	8.1
	10	426.0	24.6	1.0	.0	.25	.25	1.5	.18	6.1
8-inch mulch	5	1,119.5	49.3	.5	.5	.5	.0	1.5	.10	3.0
	7	1,137.0	49.3	1.5	.0	.0	.0	1.5	.10	3.0
	11	433.5	24.6	.0	.0	.25	.25	.5	.06	2.0
10-inch mulch	6	1,156.5	49.3	.0	.0	.0	.0	.0	.00	....
	8	1,169.0	49.3	.5	.0	.25	.0	.75	.05	1.5
	12	378.0	24.6	.0	.0	.0	.0	.0	.00	....

The table shows that the comparative losses in fourteen days after irrigation from a soil without mulch and from soils protected by 4-inch, 8-inch, and 10-inch mulches were in the ratio of 45.6, 12.9, 5.3, and 1. It likewise shows that the large loss from unprotected soils, which have been irrigated, as well as the comparatively small losses from soils covered by a mulch take place for the most part during the first two days after the water is applied and that the decrease is rapid thereafter. The first fact is emphasized by figure

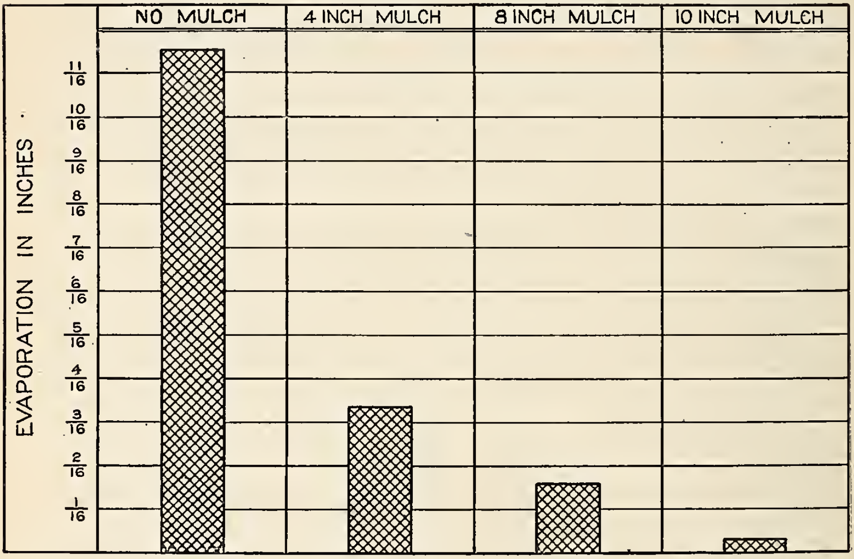


FIG. 2.—Diagram showing evaporation from soils protected by soil mulches of different depths.

2, which indicates the average loss by evaporation which occurred during a period of fourteen days from each group of tanks.

The four curved lines in figure 3 illustrate the second fact. It will be noticed that altho the amount of water evaporated is quite different for any one day, yet all four obey the same law in the rapid rate of decrease. These curves show more clearly than words can express the urgent necessity of applying the water at such depths that the surface soil will remain dry in order to lessen the waste of water by evaporation.

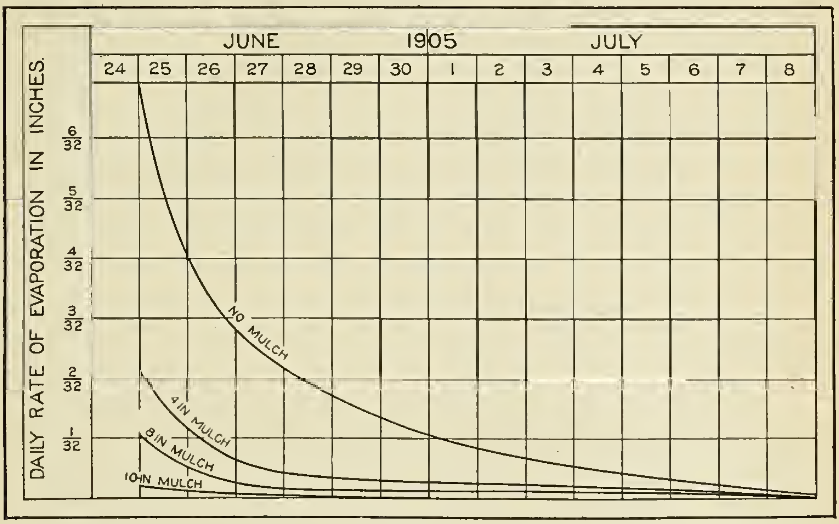


Fig. 3.—Diagram showing daily decrease in rate of evaporation from soils protected by mulches of different depths.

COMPARATIVE LOSSES OF WATER BY EVAPORATION WHEN WATER IS APPLIED AT DIFFERENT DEPTHS.

Among the fruit growers of California opinions differ as to the relative merits of shallow and deep irrigation. The general practise ten or fifteen years ago was to irrigate orchards by means of shallow furrows, spaced 2 to 2½ feet apart, or else to apply the water on the surface in basins. Basin irrigation is still practised to a considerable extent on the deciduous and walnut orchards, but in irrigating citrus trees the majority now prefer furrows. Of late years the trend of opinion has been in favor of a smaller number of furrows, but of greater depth, in which small streams of water are permitted to run fifty to seventy hours. This increase in the number of hours the water is allowed to run in furrows has not increased the total quantity applied in any one season, for there has been a corresponding decrease in the number of irrigations. Men who formerly used water for forty-eight hours every thirty days in shallow furrows use the same volume of water for seventy-two hours in deeper furrows, but with an interval of forty-five days between waterings.

This question of deep versus shallow furrows, like many more connected with farming operations, can not be definitely settled one way or another without reference to the physical conditions surrounding each case. Its solution depends, for example, on the porosity and depth of the soil, and the distribution of the roots of the trees and their depth below the surface. In a shallow soil, where the roots are near the surface, it would not be wise to destroy a large part of them in an attempt to make deep furrows, or to place the water so low in the first place that a large part would soon percolate beyond the deepest roots. On the other hand, in a deep soil, in which the amount of valuable plant food in the tenth foot may exceed that in the first foot, it would be a mistake to lure the fibrous rootlets to the surface by too frequent and shallow irrigation. It may assist fruit growers to reach proper conclusions on this question if the advantages and disadvantages of each method are briefly enumerated, and in the comparison thus made the reader may be better able to decide which method would best apply to his particular case. In the following summary " shallow irrigation " refers either to the application of water on the surface or in furrows not exceeding 3 inches in depth, while " deep irrigation " refers to the running of water in furrows 6 to 12 inches deep.

SHALLOW IRRIGATION.

ADVANTAGES.

(1) The top layer of soil is better aerated and more granular.

(2) It contains, as a rule, the largest amount of available plant food.

(3) It costs less for furrowing and cultivation.

(4) Orange trees in their native state are shallow-rooted.

(5) Artificial fertilizers are more easily applied to the top soil.

DISADVANTAGES.

(1) Shallow irrigation wastes water by excessive evaporation.

(2) It lures the fibrous roots near the surface to wilt, or kills them by subsequent drought.

(3) It tends to form an irrigation hardpan or plow sole.

(4) It restricts the feeding ground of the roots of trees.

(5) It calls for more frequent applications of water.

(6) Frequent irrigations bake or harden the surface and necessitate cultivation.

DEEP IRRIGATION.

ADVANTAGES.

(1) It conserves the moisture by checking evaporation.

(2) It distributes the water thruout the subsoil.

(3) By moistening the subsoil it tends to the deep rooting of trees.

(4) Deep-rooted trees have a larger supply of plant food within reach.

(5) Deep-rooted trees are not so injuriously affected by droughts.

(6) Deep-rooted trees require less artificial fertilizers.

(7) Deep irrigation requires less frequent application.

(8) Deep cultivation and irrigation will break up the plow sole.

DISADVANTAGES.

(1) The extra cost of furrowing and cultivating.

(2) Deep irrigation requires a correspondingly deep placing of fertilizers.

(3) Deep furrowing may injure shallow-rooted trees.

It is not the purpose of this article to discuss the relative merits of shallow and deep irrigation in all its phases. As will be observed by the foregoing outline, the subject is a broad one, and could not be fully presented in a few paragraphs. It is intended rather to take up one feature and to consider it apart from all others. The object of the experiments was to show the comparative loss of water by evaporation from shallow and deep irrigation. The range of experiments included surface irrigation and irrigation in furrows 3 to 12 inches in depth. It was an effort to settle, in a way, one of the vext questions involved in determining the proper way to irrigate orchards. In presenting the results no attempt is made to decide other matters not germane to the experiments.

In 1903 tank experiments were carried on at the substation near Pomona for the purpose of determining the losses from soils under surface and shallow-furrow irrigation. The same experiment was repeated at Riverside, Cal., during August, 1905, where use was made of larger tanks, and where a somewhat wider range was adopted. The results obtained at Riverside will be considered first.

EXPERIMENT AT RIVERSIDE, 1905.

Eight of the large tanks and three of the small tanks, both of which have already been described, were filled in the usual manner with soil from block 58, Arlington Heights Fruit Company. The soil in the tanks at the beginning of the experiment contained on an average 4½ per cent of free moisture, and the amount and distribution of free moisture at the end of the experiment were as given in the following table.

Moisture content at various depths.

Depth at which water was applied.	Six inches.	One foot.	Two feet.	Three feet.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Surface	9.7	9.8	11.5	11.4
Three-inch furrows	9.0	11.1	11.5	11.5
Six-inch furrows	9.3	11.1	11.5	11.5
Nine-inch furrows	10.6	12.2	12.0	13.1
Twelve-inch furrows	10.9	12.5	12.1	14.2

After the initial weights had been ascertained, 81½ pounds of water were applied to each of the large tanks and 40¾ pounds to each of the small tanks. The methods used in irrigating were similar to those of field practise. A furrow of the required depth was made across each tank, and water was permitted to trickle into it from the faucet of a 10-gallon can. The irrigation lasted the greater part of two days, and on the third day (August 11) the soil was dry enough to cultivate to a depth of 4 inches. On that date the top layer of soil in all the tanks was cultivated.

The temperature during the experiment is given in the following table:

Temperature at Arlington Heights, Riverside, Cal., from August 9 to 18, inclusive, 1905.

Day.	Air (sun).	Earth (sun).	Earth (shade).	Water.	Day.	Air (sun).	Earth (sun).	Earth (shade).	Water.
	°F.	*°F.*	*°F.*	*°F.*		*°F.*	*°F.*	*°F.*	*°F.*
First	92.2	119.0	90.0	82.2	Sixth	77.5	95.7	78.5	77.2
Second	84.3	109.5	81.7	80.2	Seventh	79.6	110.3	80.7	80.0
Third	78.3	102.7	78.5	83.0	Eighth	77.5	102.0	79.5	75.3
Fourth	79.3	104.0	83.5	86.8	Ninth	85.7	112.0	81.2	77.3
Fifth	79.2	104.2	83.3	85.0	Tenth	89.7	106.7	84.8	77.3

The following table gives the initial weights of the tanks, the amount of water applied, the various losses as determined by frequent weighings, and the total loss by evaporation in the ten-day period:

Evaporation from soils to which water was applied at different depths, from August 9 to 18, inclusive, 1905.

Number of tank.	Depth at which applied.	Initial weight.	Irrigation water.	Evaporation losses.							Total.		
				First two days.	Third day.	Fourth day.	Fifth and sixth days.	Seventh day.	Eighth and ninth days.	Tenth day.			
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*In.*	*Per ct.*
2	Surface	1,059.50	81.50	10.00	4.00	1.50	1.25	0.25	0.50	0.00	17.50	1.12	21.5
9		410.50	40.75	6.75	2.00	.75	1.00	.00	.50	.00	11.00	1.34	27.0
3	3-inch furrow.	1,028.25	81.50	8.75	3.00	2.25	.00	.00	1.50	.00	15.50	.99	19.0
10		402.00	40.75	5.75	1.50	1.00	.50	.25	.50	.25	9.75	1.19	23.9
4	6-inch furrow.	1,061.00	81.50	9.50	2.50	2.50	.25	.00	1.00	.00	15.75	1.00	19.3
7		1,036.25	81.50	7.75	3.00	1.25	.50	.25	.50	.25	13.50	.86	16.6
11		402.00	40.75	3.75	1.00	.50	.50	.00	.25	.25	6.25	.76	15.3
5	9-inch furrow.	1,025.75	81.50	7.75	1.00	1.25	.25	.75	1.25	.00	12.25	.78	15.0
8		1,017.50	81.50	6.00	3.00	1.75	.25	1.00	1.00	.00	13.00	.83	16.0
1	12-inch furrow.	1,078.00	81.50	5.50	1.50	2.00	.75	.00	.25	.00	10.00	.64	12.3
6		1,000.00	81.50	5.00	1.50	1.00	.50	1.00	.50	.00	9.50	.61	11.7

All the tests in this experiment demonstrate the truth of two things. One of these is that in any method of irrigation, whether it be surface, shallow-furrow, or deep-furrow irrigation, the loss by evaporation during the time when water is applied is very great. This is due to the fact that in the process of irrigation the top layer of soil becomes more or less wet and a large percentage of the amount applied is speedily evaporated. The accompanying profile (fig. 4) shows more clearly than a table of figures the daily rate of loss. The figures from which this profile was made represent the average daily evaporation from the soil in 11 tanks, and include surface irrigation as well as furrow irrigation at depths of 3, 6, 9, and 12 inches. The other fact which is so clearly indicated by the experiment is that deep furrow irrigation conserves much more moisture than surface or shallow furrow irrigation. Notwithstanding the fact that more or less of the surface soil becomes wet in deep furrow irrigation, the loss in surface irrigation in ten days was double that from furrows 12 inches deep, and the losses from furrows less deep were in proportion to their depth. This statement is made plain in figure 5, which represents graphically the loss in inches over the surface for each method of irrigation.

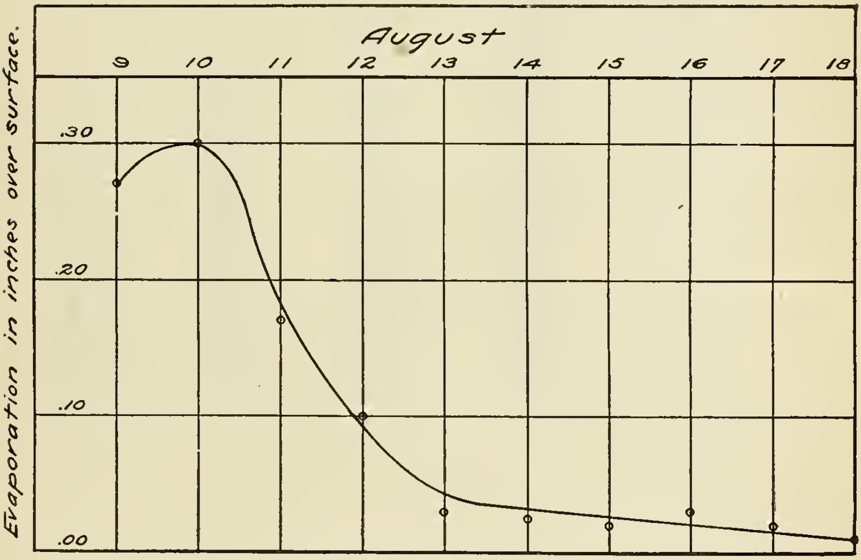


FIG. 4.—Curve showing daily rate of evaporation for ten days after water is applied.

EXPERIMENT AT POMONA, 1903.

In June, 1903, six double and water-jacketed tanks, each inner tank 17 inches in diameter and 29 inches long, were installed at the substation near Pomona. The soil used was taken from the trench in which the tanks were placed, and is elsewhere described (p. 48). The tanks were first weighed on June 20, 1903, and immediately afterwards 16 pounds of water were applied to each. Three were irrigated in shallow furrows 3 inches deep and three in furrows 12 inches deep. When dry the surface of all was cultivated.

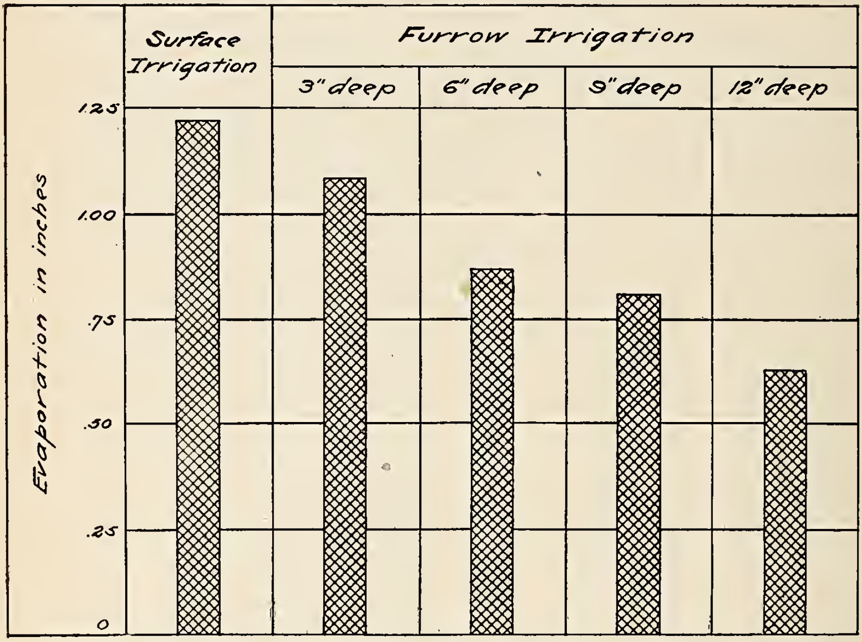


FIG. 5.—Evaporation from surface irrigation and from furrows of different depths at Riverside.

From June 20 to July 24, 1903, the loss in each tank was as follows:

Evaporation losses from soil irrigated in furrows 3 inches and 12 inches deep.

No. of tank.	Treatment.	Initial weight June 20.	Irrigation water.	Losses.		
		Pounds.	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
2	Deep irrigation	363.0	16	4.50	0.54	28.1
3	do	358.0	16	3.50	.42	21.9
4	do	362.5	16	4.25	.51	26.6
5	Shallow irrigation	351.8	16	12.75	1.53	79.7
6	do	354.0	16	17.50	2.10	109.4
7	do	359.0	16	15.00	1.80	93.7

In both cases the loss shown is less than would occur under field practise by reason of the plan adopted in applying the water. The water was applied in less than thirty minutes at the proper depth, and as soon as it was absorbed the dry soil was again placed on top. By this means little moist soil was exposed to the air and the evaporation was consequently lessened.

INFLUENCE OF SUBIRRIGATION IN CHECKING EVAPORATION.

Before discussing subirrigation it may be well to explain the difference between what may be called artificial subirrigation by means of underground pipes and subirrigation by seepage from ditches and laterals. The former method has been tried by the owners of gardens and orchards in California for the past twenty-five years, but without success. Yet it is generally considered by those who are best qualified to judge, that this is an ideal method of applying water. It possesses most of the advantages, with few of the disadvantages of other methods. If it were practicable to apply water at the desired depth below the surface, the cost of grading and leveling the surface would be much reduced, because a smooth-graded surface would not be required; the puddling and consequent baking of the surface layer of soil would be avoided; moisture would rise from beneath and not descend from the surface, thereby interfering with the amount and circulation of the air in the open space in the soil; well pulverized dry soil mulches, which retain the moisture in gardens and orchards, would be less affected by each irrigation; there would be no check levees, field laterals, or basin checks to impede the operations of farm implements; and, most important of all, much of the water, which by the other methods of irrigation is allowed to pass into the air by evaporation, would be retained in the soil.

Notwithstanding its many advantages, artificial subirrigation has been confined to small areas. The reasons for this lack of success may be readily stated. In the first place subirrigation by means of pipes below the surface is best adapted to deep-rooted plants in deep soil. It is true this method is successfully followed in greenhouse irrigation, but under field conditions it would be impracticable, to say the least, to attempt to moisten the surface layer of soil by means of subsurface pipes in order to nourish shallow-rooted crops. The expense necessary to lay pipes beneath the surface sufficiently near to each other to permit the wetting of the soil between the rows of pipes is another serious objection. Even after the piping is laid there are difficulties to be overcome. The roots penetrate the joints of pipe and choke the passage. Water does not percolate laterally as rapidly as it does vertically, the moisture is not evenly distributed over the root zone, and it is an extremely difficult problem in hydraulics to distribute water equally thru a large number of openings in an underground system of pipes.

While artificial subirrigation thru underground pipes has been seldom practised except in greenhouse irrigation, natural subirrigation from laterals, ditches, and the channels of streams is gaining in favor. In Fresno County, Cal., a part of the 75,000 acres in grapevines is now subirrigated from ditches and laterals. As a result of furrow and check irrigation in former years, the water-table has risen near enough the surface to enable the deep roots of the vines to draw water from beneath. It is only when the water-table recedes too far beneath the surface that the plants begin to suffer from lack of moisture, and an additional supply is furnished once or twice a year by filling the ditches and laterals and permitting the water to seep into adjacent subsoils.

In many parts of the mountain States where the conditions are favorable, subirrigation from ditches is resorted to as the best means of wetting the soil. The conditions most favorable for this practise are a reasonably steep, even slope, and the surface soil underlaid by an even stratum of sand or gravel resting on a bed of clay or other impervious material. By making ditches along the upper borders of a field and raising the water by means of checks, it is frequently possible to subirrigate from 10 to 40 acres without the use of laterals or furrows. An open friable soil from 1 to 2 feet in depth resting on a clay subsoil will also subirrigate, but in smaller tracts.

Two tank experiments have been made in California for the purpose of determining the influence of subirrigation in checking the loss of water by evaporation. Water was applied at different depths below the surface in such a manner as not to disturb the surface layer of soil. The many factors entering into a consideration of this question, apart from that of loss of water by evaporation, were not included and formed no part of either experiment. The first experiment was carried on at the substation near Tulare, Cal., in the summer of 1903, and the second near Riverside in the summer of 1905. Inasmuch as the latter was the larger and more carefully conducted test it will be first described.

SUBIRRIGATION EXPERIMENT AT RIVERSIDE, CAL.

In the Riverside experiment, eight of the large water-jacketed tanks were used. The kind of soil used, the manner of placing it, and the apparatus used for weighing were the same as those described in previous experiments. In tanks 1 and 5 were placed tin tubes 1 inch in diameter, with small holes 1½ inches apart along opposite sides. A tube was placed in a horizontal position across each tank, 12 inches below the surface. Leading to each tube was a vertical tube of the same diameter thru which water was allowed to trickle from a 10-gallon can above. In tanks 2 and 6 similar tubes were placed 9 inches below the surface; in tanks 3 and 7 they were placed 6 inches below, while in tanks 4 and 8 they were placed 3 inches below the surface. Before weighing, 2 inches of dry-soil mulch was placed on the surface of each tank.

The soil contained at the beginning of the experiment on August

23, 1905, the following average percentages of free water at different depths:

	Per cent.
6 inches below surface	4.19
12 inches below surface	3.79
24 inches below surface	4.42
36 inch below surface	4.96
Average	4.34

The valve was so adjusted that it required forty-two hours for the contents of the 10-gallon can to pass thru the tubes into the subsoil. It was quite noticeable that in the deeper tubes the water disappeared more quickly than in shallow tubes.

The accompanying diagram (fig. 6) shows the appearance of the surface of the tanks as regards moisture at five different times during the first sixty-three hours, the shaded areas representing wet soil.

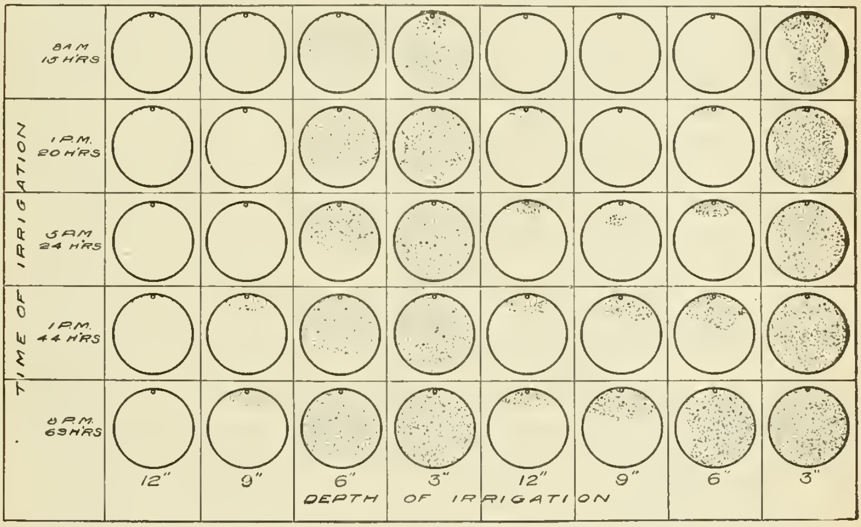


FIG. 6.—Diagram showing appearance of moisture on surface during subirrigation experiment.

At the beginning of the experiment there was little difference between moisture content at the top of the tank and that at a depth of 24 inches, the average for all being 4.34 per cent of free moisture. Ten days later, at the end of the experiment, the soil moisture conditions were as shown in the following table:

Moisture content of tanks at end of ten days.

Depth below surface.	Water applied at depths of—			
	Three inches.	Six inches.	Nine inches.	Twelve inches.
6 inches ......per cent..	5.7	6.02	7.79	8.15
12 inches ......do....	8.35	8.66	8.32	8.68
24 inches ......do....	11.14	11.23	10.40	11.31
36 inches ......do....	13.70	13.32	13.40	14.90

This table shows that below the 6-inch level the increase in the moisture content of the soil was about the same in all the tanks, but in the upper layer of soil the percentage of moisture increased with the depth at which the water was applied, showing that, contrary to what might be expected, the application of water at considerable depth increases the quantity of water retained by the soil, even in the top layer.

In the following table, in which only the means of duplicates are given, are to be found the initial weights of the soil, the amount of water applied, the periodical losses, and the total losses by evaporation in a period of ten days. In experimenting with a unit of 8¾ cubic feet of compacted soil weighing, with the vessel, about 1,200 pounds, and ascertaining its weight by means of platform scales, it was not possible to determine the exact loss for each day, for the amount was frequently too small to be precisely weighed. This may account for some apparent discrepancies, as, for example, in the losses given in the twenty-four-hour period from August 30 to 31. On the whole, however, and for losses weighing 1 pound or more, it is believed the results are accurate.

Evaporation from soils to which water was applied at different depths below the surface at Riverside, Cal.

Number of tank.	Initial weight of tank.	Irrigation water.	Depth at which water was applied.	Evaporation losses.									
				Aug: 23–25.	Aug. 25–28.	Aug. 28–29.	Aug. 29–30.	Aug. 30–31.	Aug. 31–Sept. 2.	Total loss.	Average loss per day.	Amount applied.	Depth.
Mean of—	*Lbs.*	*Lbs.*	*In.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*	*In.*
1 and 5	1,217.00	83.5	12	2.25	1.75	0.50	0.50	0.00	0.00	5.00	0.50	6.0	0.32
2 and 6	1,196.90	83.5	9	4.38	1.38	.75	1.13	.38	.50	8.52	.85	10.2	.55
3 and 7	1,229.38	83.5	6	6.88	4.38	1.00	1.00	.38	1.38	15.02	1.50	18.0	.96
4 and 8	1,243.13	83.5	3	9.75	7.00	1.63	1.00	.13	1.38	20.89	2.08	25.0	1.34

The evaporation was much greater during the first two days, and at the end of the first five-day period it was 77 per cent of the total loss which occurred in the ten-day period.

CLIMATIC CONDITIONS.

The weather during this ten-day period, from August 23 to September 2, 1905, was neither cool nor excessively hot, but was typical of much of the agreeable summer weather so prevalent at Riverside. During the first three days the temperature in the shade from 8 a. m. to 5 p. m. varied from 71° to 93½°, and for the balance of the time the temperature rose several degrees, reaching a maximum at 1 p. m. on August 29, when it was 106½°.

In the following table are given the records of temperature taken from August 23 to September 2, 1905, of the air in the shade and in the sun, of the surface of the earth in the shade and in the sun, as well as moist earth, and the temperature of the surface of the water in the evaporation tank:

Temperature at Arlington Heights, Riverside, Cal., from August 23 to September 2, inclusive, 1905.

Time.	Air.		Earth.		Water in sun.	Moist earth.	Weather.
	In shade.	In sun.	In shade.	In sun.			
August 23:	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	
5 p. m	81½	81½	87½	91½	77½	....	Cloudy.
August 24:							
8 a. m	71½	72½	71½	80½	73	....	Do.
1 p. m	92½	94	91	130	86½	....	Clear; breezy.
5 p. m	81½	83	85½	95	78	74	Clear.
August 25:							
8 a. m	71	79	68½	86	74½	78½	Do.
1 p. m	93½	95½	93½	126	85	91½	Clear; breeze.
5 p. m	85½	86½	85½	105	77½	76	Clear.
August 26:							
8 a. m	74½	78	68½	93	72½	77	Do.
1 p. m	92½	103	101½	138½	88	89½	Clear; hot wind.
5 p. m	91	93	91	105	78	77	Clear.
August 27:							
8 a. m	81½	87	75	93	74	85	Do.
1 p. m	103½	103½	100	143	88½	93	Hot wind.
5 p. m	98	101	99	120	82	89	Cloudy.
August 28:							
8 a. m	85	88½	77	101½	75	84	Clear.
1 p. m	103	107	106½	141½	90	114	Do.
5 p. m	93	95	94½	106	82	Dry.	Do.
August 29:							
8 a. m	84	91	76	98	74½	76	Do.
1 p. m	106½	107½	102	135	88	Dry.	Hot wind.
5 p. m	99	101	98½	113	87½	Dry.	Do.
August 30:							
8 a. m	81	87½	74	93	74½	....	Clear.
1 p. m	104½	105	103½	140	87½	....	Do.
5 p. m	94	96	94	111	79	....	Do.
August 31:							
8.15 a. m	83½	89½	75	93	73½	....	Do.
1.15 p. m	100½	101½	101½	132	87	....	Breeze; clear.
5 p. m	91	91	92½	106½	78½	....	
September 1:							
8 a. m	75	79	70½	95	73½	....	Slightly cloudy.
1 p. m	97½	101	97½	136	86½	....	Clear; breeze.
5 p. m	90	93	91	105	78	....	Clear
September 2:							
8 a. m	72½	82	67½	95	72½	....	Do.
1.15 p. m	92	94	96	130	84½	....	Breeze; clear.

The main fact to be emphasized in this experiment is the effect produced by shallow and medium-deep subirrigation in checking evaporation. In nearly two days enough water to have covered the surface to an average depth of 5⅓ inches was applied. When the water was applied 12 inches below the surface the loss in 10 days was only 6 per cent, or what would correspond to one-third of an inch over the surface. When it was applied 9 inches below the surface, the loss was 10 per cent, or one-half inch; when applied 6 inches below the surface, the loss was 18 per cent, or about 1 inch, and when the water was applied 3 inches below the surface, the loss was 25 per cent, or about 1⅓ inches.

SUBIRRIGATION EXPERIMENT NEAR TULARE, CAL.

The purpose of this experiment, which was begun by A. P. Stover on May 30, 1903, was to determine the difference in the loss by evaporation between ordinary irrigation applied on the surface and subirrigation applied at a depth of 2 feet below the surface. In the latter case tin tubes similar to those already described in the Riverside experiment were used to distribute the water at the proper depth. Each of the tanks used was double jacketed and of the following dimensions: Inside diameter, 17 inches; depth, 29 inches; weight with bale, 34½ pounds. The following varieties of soil were used in the experiment: Nine tanks were filled with sandy loam containing a considerable quantity of alkali obtained on the grounds of the substation; 6 tanks were filled with dark loam containing a fair proportion of organic matter and a little alkali; three tanks were filled with coarse sandy soil containing alkali; and the other three tanks were filled with strong alkali soil from the substation grounds which contained too much alkali to be productive. All these tanks were installed in sets of three, two of which were irrigated on the surface, and in the third of each set the water was applied thru perforated pipes at a depth of 2 feet in imitation of subirrigation. The amount of moisture in the soil was not ascertained.

In the following table is given only the mean, or average, of the results of several tanks which contained the same kind of soil and which were watered in the same way.

Evaporation losses from surface irrigation and from subirrigation 2 feet below the surface near Tulare, Cal., May 30 to June 24, 1903.

Kind of soil.	Initial weight May 30.	Weight of water applied.	Loss by evaporation in 26 days.		
	Pounds.	*Pounds.*	*Pounds.*	*Per cent.*	*Inches.*
Sandy loam:					
Surface irrigated	312.7	57.6	34.7	60.0	4.22
Subirrigated	326.0	57.6	6.1	10.6	.74
Sandy soil:					
Surface irrigated	362.0	57.6	29.9	5.9	3.64
Subirrigated	368.5	57.6	5.1	8.9	.62
Dark loam:					
Surface irrigated	294.4	57.6	46.2	80.2	5.63
Subirrigated	297.0	57.6	16.1	28.0	1.93

Equal amounts of water were applied to the tanks on May 30, June 6, June 13, and on June 20, the total being 57.6 pounds, corresponding to a depth over the surface of 7.02 inches. The average loss in twenty-six days from the three different soils which were surface irrigated was 4.49 inches, and the average from the same soils subirrigated was 1.11 inches, or a gain of 4 to 1 in moisture conservation in favor of subirrigation.

The three tanks which were filled with strong alkali soil were not included in the above table, for the reason that such salts tend to keep the surface moist by drawing moisture from beneath. This is plainly indicated in the experiment, the results of which are as follows:

Evaporation losses from alkali soil.

Treatment.	Initial weight.	Water added.	Loss by evaporation.		
	Pounds.	*Pounds.*	*Pounds.*	*Per cent.*	*Inches.*
Surface irrigated	305.3	57.6	35.7	62.0	4.35
Subirrigated	303.0	57.6	23.1	40.0	2.81

Both experiments show that if water could be applied to crops beneath the surface and without wetting the top soil, there would be less evaporation than when water is applied by any method now practised. While the practise of artificial subirrigation by means of pipes laid beneath the surface is now seldom used, that of natural subirrigation from ditches and canals is becoming more common.

In the natural subirrigation of soils the loss by evaporation is much greater from shallow soils than from deep soils. In the Riverside experiments the evaporation loss in ten days from orchard soil which was irrigated 3 inches below the surface was more than four times as great as that from like soil which had been irrigated 12 inches below the surface. In the Tulare experiments soil which was subirrigated 3 inches below the surface lost in twenty-six days 4½ inches in depth over the surface out of 7 inches applied, whereas similar soil to which water was applied 24 inches below the surface lost only 1.1 inches.

EVAPORATION FROM MOIST AND DRY SOILS.

EXPERIMENT AT TULARE, CAL.

In June, 1904, an experiment was begun at the substation near Tulare, Cal., to determine the effect of the moisture content of soils upon the rate and amount of evaporation. Twelve double, water-jacketed tanks, of which the inner of each pair was 17 inches in diameter and 30 inches deep, were used. The lower third of each tank was filled with sandy loam from an adjacent barley field which contained some alkali, while dark sandy loam free from alkali and containing a considerable amount of vegetable matter was placed in the upper two-thirds of each tank. The experiment was planned in such a way that all conditions would be as nearly similar as it was possible to make them, with the exception of the amount of water applied to each pair of tanks. The experiment was carried on in duplicate. Tanks 1 and 2 received no irrigation water, tanks 3 and 4 received 2 quarts every two weeks, tanks 5 and 6 received 3 quarts, and so on, the increase being gradual up to the last pair, which received 6 quarts of water every two weeks. It will be observed that the amount of water applied was small in all cases. The smallest amount applied every two weeks was equivalent to a depth over the surface of half an inch, and the largest amount to a depth of 1½ inches. Even the latter is considerably less than is commonly applied for crop production. It amounted to 9.8 inches in depth over the surface for the season from June 15 to September 15. In carrying on the experiments the tanks were weighed as often as possible and the water was put on after the weights were ascertained. On the day following the surface was cultivated a few inches deep. The following table gives the results of the experiment:

Evaporation from Tulare soils which received different amounts of water, June 15 to September 15, 1904.

Numbers of tanks.	Initial weight of soil.	Amount of water applied.		Loss by evaporation.		
	Pounds.	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Per cent.*
1 and 2	319.5	0.0	0.0	3.8	....	....
3 and 4	324.0	27.4	3.3	29.1	3.5	106.0
5 and 6	317.8	41.0	4.9	38.5	4.6	94.0
7 and 8	314.0	54.7	6.6	45.7	5.5	83.6
9 and 10	311.5	68.4	8.2	54.7	6.6	80.0
11 and 12	316.3	82.1	9.8	65.3	7.9	79.5

The total moisture content of the soil at the beginning of the experiments averaged 7.73 per cent. This would be equivalent to over 25 pounds of water in each tank, or 3 inches in depth over the surface. The table shows that tanks 1 and 2, which received no water, lost on an average 3.8 pounds each, or about 0.45 inch over the surface, this amount having been evaporated from the moisture

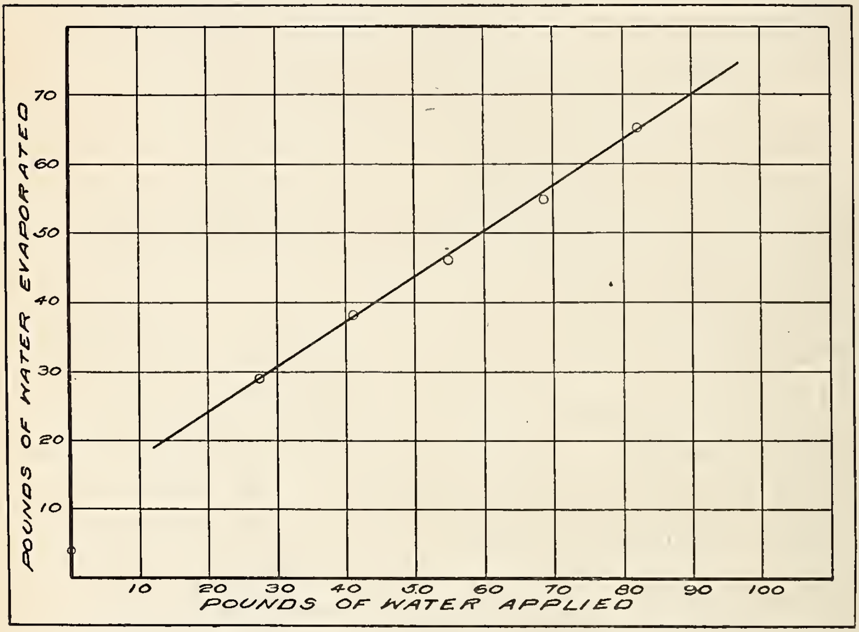


FIG. 7.—Diagram showing relation between amount of water and loss by evaporation as determined by experiments with Tulare soils, June 15 to September 15, 1904.

in the soil at the beginning of the experiment. The table also shows that in tanks 3 and 4 all of the irrigation water was evaporated and 1.7 pounds of the initial soil moisture. More water was applied to tanks 5 and 6 and 94 per cent was evaporated. Still more was applied to tanks 7 and 8 and 84 per cent was evaporated, while in tanks 11 and 12 the maximum amount was applied, of which 79.5 per cent was evaporated. These percentages decrease gradually as the amount of water applied increases, but there is a considerable increase in the absolute amount lost as the amount applied increases.

Figure 7 would seem to indicate that for tanks 3 to 12, inclusive. which were irrigated, the relation existing between the water applied and that evaporated may be exprest in the form $x = ay + b$, in which y represents the irrigation water measured in pounds and x the number of pounds of soil moisture evaporated.

EXPERIMENT AT RIVERSIDE, CAL.

A somewhat similar experiment was conducted on block 58, Arlington Heights Fruit Company, near Riverside, Cal., from July 27 to August 5, 1905. In this experiment eight jacketed tanks were used. Each of the inner tanks was 23½ inches in diameter and 47 inches deep and held from 1,000 to 1,200 pounds of soil. Each tank was filled with sandy loam taken from a trench which was dug in the orange orchard, and placed with its top rim nearly level with the surface. As before, the experiment was carried on in duplicate, the eight tanks being divided into four groups. The first group, or pair, received no water; the second group received 40 pounds each or an equivalent of 2.56 inches in depth over the surface; the third 70 pounds each, or 4.48 inches; and the fourth 100 pounds each, which corresponded to a depth of 6.4 inches over the surface. The experiment lasted ten days and during this time each tank was weighed seven times. At the completion of each set of weighings the evaporation loss in pounds from each tank was figured out and an equal weight of water was added so as to maintain a constant percentage of moisture in each pair thruout the experiment. The soil was not cultivated.

The following figures represent the average amount of free moisture in the soils of each group. In the second column is given the moisture content before any water was applied, and in the third the total amount after water was applied. It will be noted that the soils at the beginning of the experiment ranged from a dry soil containing only 4.8 per cent of the free moisture to a very wet soil containing 17.5 per cent of free moisture.

Percentage of free moisture[a] in soil.

Numbers of tanks.	Before irrigation.	After irrigation.
1 and 3	4.8	4.8
2 and 4	4.6	8.9
5 and 7	4.5	11.9
6 and 8	6.8	17.5

[a] The additional hydroscopic moisture averaged 5½ per cent.

The condition of the weather during the experiment was clear, altho somewhat cool for midsummer in that locality. Slight fogs occurred occasionally in the morning. The temperature records relating to the experiment are given in the following table, in which the temperatures of both earth and water were taken about three-eighths inch below the surface, or just sufficient to cover the bulb of the thermometer:

Average temperature at Arlington Heights, Riverside, Cal., from July 27 to August 5, inclusive, 1905.

Date.	Air (sun).	Earth.		Water.	Date.	Air (sun).	Earth.		Water.
		Sun.	Shade.				Sun.	Shade.	
1905.	°*F.*	°*F.*	°*F.*	°*F.*	1905.	°*F.*	°*F.*	°*F.*	°*F.*
July 27	84.5	104.0	79.0	85.4	Aug. 1	93.0	113.3	86.7	80.8
28	75.8	105.3	78.2	79.6	2	76.2	97.0	78.2	77.0
29	80.7	106.7	84.0	81.3	3	80.8	109.3	77.5	77.7
30	76.3	101.5	79 8	83.7	4	84.7	113.2	79.8	79.7
31	84.5	89.8	77.3	76.2	5	90.3	122.1	88.0	80.3

The results of the experiments are briefly summarized in the following table, which gives only the averages of each group:

Evaporation from soils at Arlington Heights.

Numbers of tanks.	Initial weight of soil and tank.	Amount of water added.	Loss by evaporation in ten days.		
	Pounds.	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
1 and 3	962.4	0	6.3	0.4	....
2 and 4	940.8	40	15.4	1.0	38.5
5 and 7	941.5	70	19.1	1.2	27.3
6 and 8	950.0	100	23.9	1.5	23.9

The accompanying diagram (fig. 8) may convey a clearer idea of the relation between soil moisture and evaporation. In it is shown for each pair of tanks, taking the average of all duplicates, the original amount of free water in the soil, the amount added, and the loss by evaporation in ten days.

Figure 9 likewise corroborates the Tulare experiments in showing that in the case of all the tanks which were irrigated at the beginning of the experiment the relation existing between the water applied and that evaporated may be exprest in the form $x=ay+b$. in which y represents the former and x the latter.

Of late years some of the chemists of western experiment stations,[a] in taking samples of soil at different depths, both before and after irrigation, have found the same thing as shown by these experiments; but the information thus derived has not been readily understood by the farmers, and it is doubtful if many have modified their methods

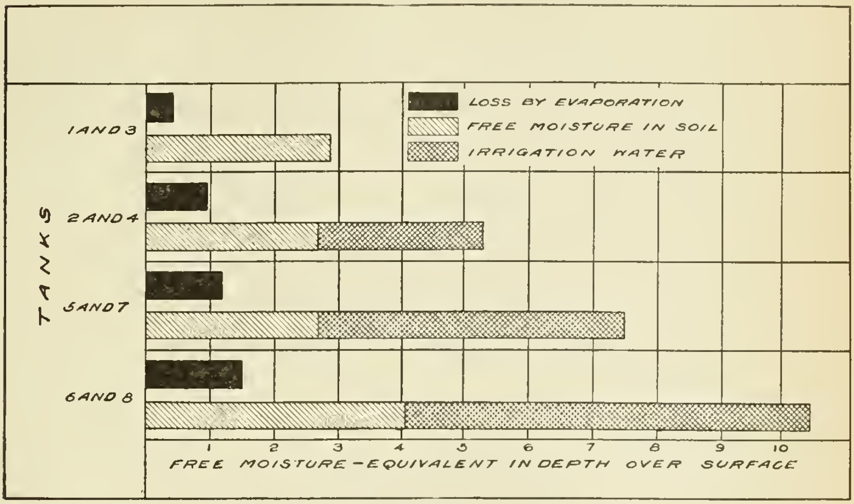


FIG. 8.—Diagram showing the initial amount of free moisture in the soil, the amount added, and the loss by evaporation, July 27 to August 5, 1905, at Riverside.

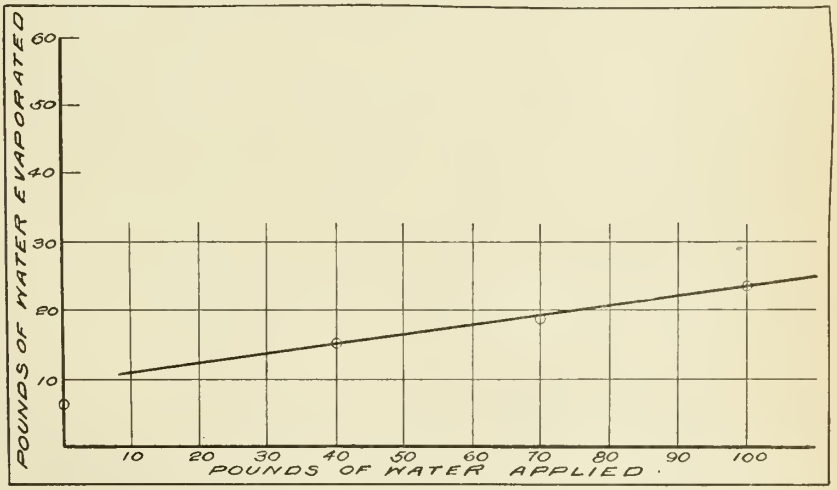


FIG. 9.—Diagram showing relation between amount of water and loss by evaporation as determined by experiments with Riverside soils.

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[a] The reader is referred to an article on the effect of the initial percentage of moisture in Utah Sta. Bul. 80.

of irrigation and cultivation as a result of this recently discovered principle. Yet this principle—which may be stated thus: the rate of evaporation from soils varies directly with the amount of moisture in the top layer—appears to lie at the foundation of good irrigation practise. To ignore it can not but result in much waste of water. He who keeps the surface of his fields moist by long-continued or frequent irrigations, and who fails to cultivate the surface whenever it is practicable after each irrigation, will lose by evaporation a large part of the water applied. On the other hand, he who keeps the top soil dry or wets it only at long intervals, and cultivates often and thoroly, will conserve the greater part in the soil.

INFLUENCE OF TEMPERATURE ON EVAPORATION.

In connection with the tank experiments with soils, measurements of evaporation from water surfaces have been made at Chico, Berkeley, Tulare, Pomona, and Calexico. The tanks were 22 to 36 inches in diameter, 30 inches deep, and were set in the ground with their rims 1 inch or less above the ground. Readings have usually been made weekly. At Chico, Tulare, and Pomona the tanks have been on the substations of the California Agricultural Experiment Station, and the observers have been those in charge of the substations.[a] At Berkeley the observer has been E. F. Griffith, of the Irrigation and Drainage Investigations, and at Calexico the measurements have been made by J. E. Peck, of the engineer's office of the California Development Company. The records gathered are not equally complete for the five stations, having been begun in 1903 at Tulare, Pomona, and Calexico, and in 1904 at Chico and Berkeley.

The total monthly and annual evaporation for each of the five stations are given in the summary below:

Monthly and annual evaporation, California stations, 1903, 1904, and 1905.

Month.	Chico.		Berkeley.		Tulare.			Pomona.			Calexico.		
	1904.	1905.	1904.	1905	1903.	1904.	1905.	1903.	1904.	1905.	1903.	1904.	1905.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
January	0.50	0.09	......	1.00	......	1.46	1.46	......	2.78	1.93	......	4.39	2.72
February	1.06	1.21	......	1.36	......	2.98	2.50	......	2.57	1.65	......	6.32	1.74
March	1.10	3.77	......	2.11	......	3.80	2.90	......	3.69	3.73	......	8.86	4.44
April	2.97	4.79	......	3.14	......	4.63	3.32	......	5.00	4.08	......	9.55	4.74
May	5.60	6.82	......	4.70	......	7.95	6.80	......	6.50	5.98	......	10.91	8.38
June	6.78	9.07	......	5.68	......	10.66	10.34	......	8.20	7.73	......	13.89	12.86
July	8.34	10.00	......	5.52	......	12.20	11.07	9.07	9.34	8.93	14.48	12.47	10.43
August	7.66	9.57	......	5.09	12.34	12.00	7.60	9.37	9.37	9.02	12.72	10.98	8.52
September	4.79	7.53	......	4.65	9.05	8.66	6.25	6.29	7.23	7.45	10.29	8.61	7.83
October	2.18	5.73	2.84	4.27	6.32	4.25	[a]4.82	6.63	5.37	5.28	7.50	8.78	6.77
November	1.55	3.37	1.44	2.68	3.51	3.88	[a]3.88	4.25	4.05	[b]4.05	4.80	5.40	3.23
December	.95	1.52	1.01	1.35	2.00	2.00	2.00	2.51	2.94	[b]2.94	4.52	3.48	3.43
Annual	43.48	63.47	......	41.55	......	74.47	62.94	......	67.04	62.77	......	103.64	75.09

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[a] Since February, 1905, the tank at Chico has been at the plant-introduction garden, and observations have been made under the direction of P. H. Dorsett, who is in charge of the garden.

[b] Interpolated from previous year's record.

The stations for which records are complete for two years are Chico, Pomona, and Calexico. The records for Tulare and Pomona have been made to cover two years by using for November and December, 1905, the figures for the same months for 1904. The totals for Tulare and Calexico show a variation of from one-sixth to one-half for the two years, indicating the desirability of additional observations to give a reliable mean. There is also seen to be considerable change by months for the several years, altho these variations are of course to be expected. The most interesting feature of the results is the large amount of the annual evaporation at some of the stations. At three of these stations the loss for July reached over 10 inches, and at Calexico, for July, 1903, it is seen to have reached the excessive figure of 14.48 inches.

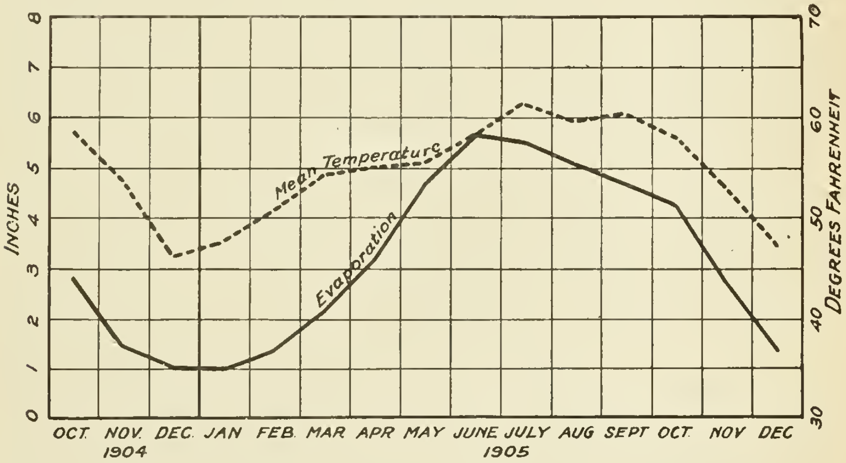

FIG. 10.—Diagram showing relation between temperature and evaporation at Berkeley, Cal.

The weekly rates of evaporation are not given in the table. During the winter months the loss was practically nothing at some of the stations, never falling below 0.25 inch for a week, however, at Calexico. The maximum weekly rates for the five stations were 2.8 inches for Chico, from June 24 to July 1, 1905; 1.55 inches for Berkeley, from July 8 to July 15, 1905; 3.25 inches for Tulare, from August 1 to August 8, 1903; 3 inches for Pomona, from July 11 to July 18, 1903, and 3.75 inches for Calexico, from June 25 to July 2, 1904.

To illustrate the well-known effect of temperature on evaporation, the monthly mean temperatures and the monthly evaporation have been platted together for each of the stations (figs. 10, 11, 12, 13, and 14.) Only at Calexico was there any decided departure from the general rule that the evaporation increases and decreases with increases and decreases in the mean temperature. The apparent marked departure at Calexico during July and August of each year may be due to the fact that the temperatures given are for Imperial rather than for Calexico, there being no records available for the latter place. This, however, is not probable. No effort has been made to adapt the scale of inches and degrees so as to show any quantitive relation. The aim is merely to show that the variation is approximately consistent.

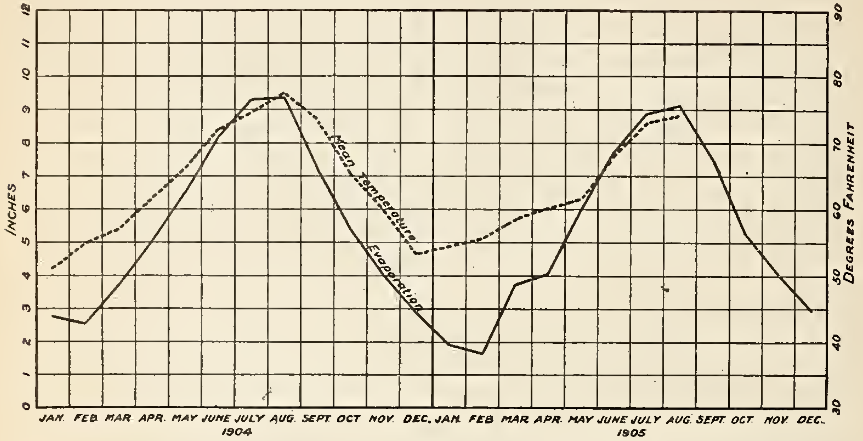

FIG. 11.—Diagram showing relation between temperature and evaporation at Pomona, Cal.

In the summer of 1904 five galvanized-iron tanks, 22 inches in diameter and 28 inches deep, were sunk into the ground in the experimental field at Berkeley for testing under field conditions the influence of the temperature of the water surface on evaporation. Ice-water jackets were placed around two of the tanks for the purpose of

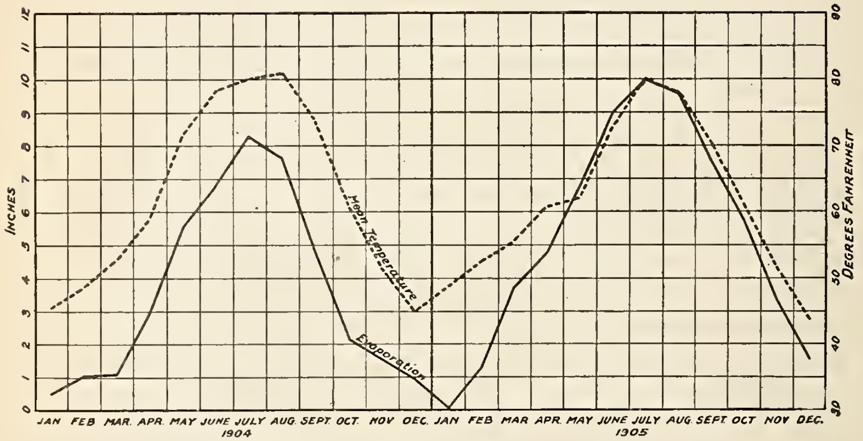

FIG. 12.—Diagram showing relation between temperature and evaporation at Chico, Cal.

reducing the temperature, and kerosene lamps were placed under two for the purpose of increasing the temperature.[a] For a period of

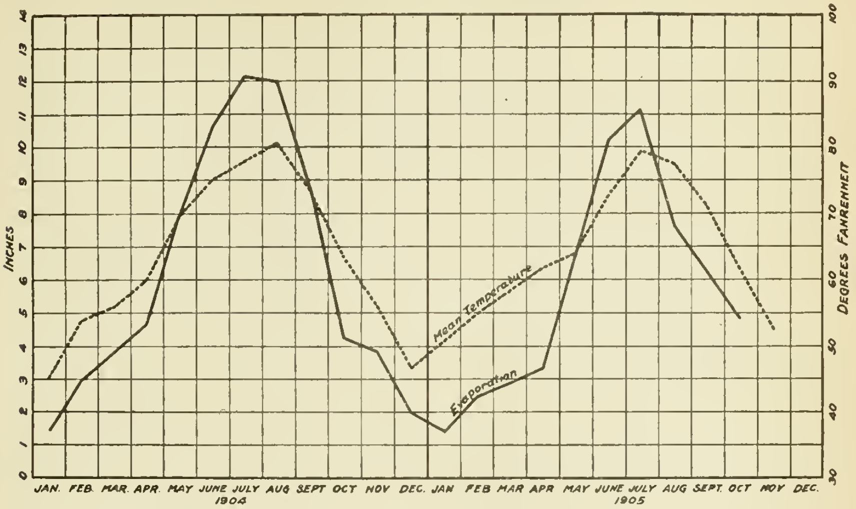

FIG. 13.—Diagram showing relation between temperature and evaporation at Tulare, Cal.

thirty days, from July 20 to August 20, readings of temperatures were taken at 3, 6, 7, 9, and 11 a. m., and at 1, 3, 5, 9, and 12 p. m.,

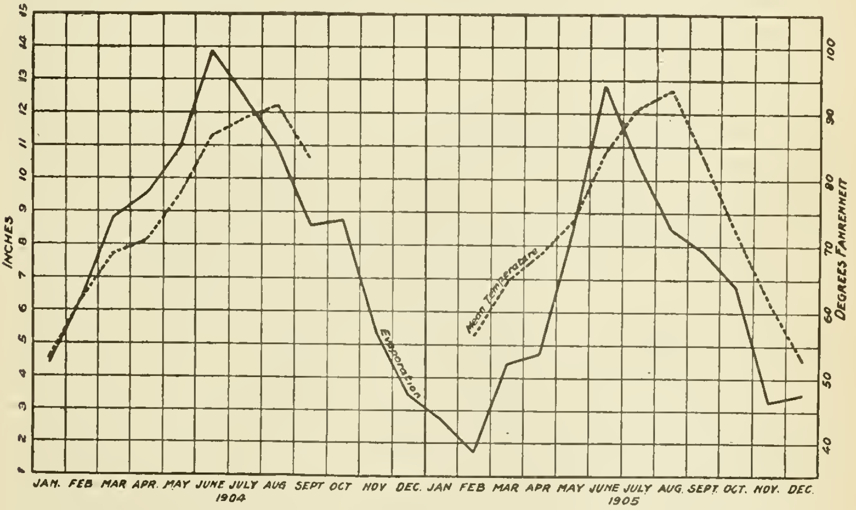

FIG. 14.—Diagram showing relation between temperature and evaporation at Calexico, Cal.

and an effort made to keep the five tanks at temperatures of 50°, 60°,

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[a] Placing the kerosene lamps below the tanks of course involved heating the entire body of water in each tank rather than the surface only. The comparative results in this way, and in heating from above, are not known, but it is not likely that they are largely different in their effects on total evaporation.

70°, 80°, and 90° Fahrenheit, respectively. At the same time measurements of the amount of evaporation were made with a hook gage reading to one sixty-fourth of an inch. A thermograph kept a continuous record of air temperatures, and water temperatures were read by means of a small detached thermometer. Mr. H. T. Nowell, a senior student in civil engineering in the University of California, was placed in charge of the tanks as observer. In 1905 similar experiments were made at Tulare, Chico, and near Lone Pine, the latter in Owens Valley, with Mr. Nowell still acting as observer, the idea being to come in contact also with conditions typical of the San Joaquin and Sacramento valleys and with the dry interior country of Owens Valley, where the elevation is considerably greater than at Berkeley, Tulare, or Chico. The plan of the experiments was not materially changed in 1905 from that followed at Berkeley in 1904, excepting that the records were taken at intervals of three hours during the daytime and sometimes only once between 9 p. m. and 6 a. m. At Soldiers Camp, near Lone Pine, ice was not available for cooling tanks 1 and 2, as at Berkeley, Tulare, and Chico, and so no attempt was made to keep tank 1 at a temperature of 50°, altho by the use of snow packed from the neighboring eastern slope of Mount Whitney, and cold water siphoned to the water jacket from Lone Pine Creek near by, tank 2 was kept approximately at the 60° desired.

The results of the observations at the four stations are summarized as follows:

Summary of observations on the influence of the temperature of the water surface on evaporation.

Place.	Date.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 4.		Tank No. 5.	
		Average temperature water surface.	Average daily evaporation.	Average temperature water surface.	Average daily evaporation.	Average temperature water surface.	Average daily evaporation.	Average temperature water surface.	Average daily evaporation.	Average temperature water surface.	Average daily evoporation.
		°F.	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*	*°F.*	*Inch.*
Berkeley	July 20–Aug. 20, 1904	55.5	0.06	62.0	0.11	69.2	0.22	80.1	0.44	89.2	0.56
Tulare	June 12–27, 1905	51.9	.09	61.3	.17	76.2	.40	80.4	.44	88.	.57
Chico	July 8–23, 1905	52.9	.12	61.6	.22	79.4	.40	81.0	.45	89.1	.58
Soldiers' Camp, near Lone Pine.	Aug. 2–13, 1905	......	......	60.1	.25	69.4	.42	80.2	.60	87.7	.70
Mean		53.4	.09	61.3	.19	73.5	.36	80.4	.48	88.7	.60

The mean figures on the bottom line give an epitome of the results of the observations. Where the average temperature of the water surface was 53.4° Fahrenheit, the daily evaporation was 0.09 inch. Where the temperature was 61.3° the evaporation was twice as much. Where the mean temperature was 88.7° it was seven times as much.

With water temperatures approximating 60° the daily loss increased more than double from Berkeley to Soldiers' Camp. Where the temperature approximated 90° the evaporation was less than one-third more at Soldiers' Camp than at Berkeley. The increase at Soldiers' Camp over the other stations was in part due to the increased wind velocity, it averaging 4 miles per hour there and 2.4 to 2.87 miles per hour at the other stations. It was also in part due to the drier air at Soldiers' Camp, altho to what extent is not known.

In arid America the days are warm and the nights cool. This fact is illustrated in the accompanying diagram (fig. 15), which shows the hourly temperatures of the air in an orange orchard at Arlington Heights, Riverside, Cal. The figures from which the diagram was made are the mean of a number of observations and the result may be considered a fair representation of the fluctuation, during summer, in air temperatures in that locality. It will be observed that the average temperature from 7 o'clock in the evening to 7 o'clock the following morning is 59°, and that the average temperature during the twelve-hour day period is 83°, a difference of 24° between night and day.

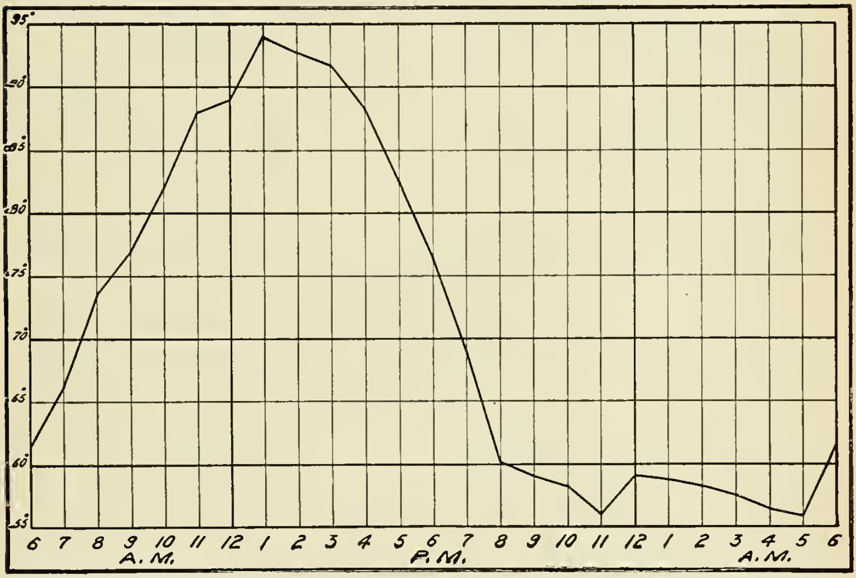

FIG. 15.—Diagram showing hourly temperatures in an orchard at Arlington Heights, Riverside, Cal.

Again, the temperature of the surface of a bare soil, such as is found between the tree rows of a cultivated orchard, is much higher than that of the surrounding air in the sun. This is clearly shown in figure 16, which represents the hourly records of both at Arlington

Heights, on September 29, 1905. From 7 a. m. to 5 p. m. the temperature of the soil averaged 22° higher than that of the air. At 5 p. m. the soil was shaded by the orange trees.

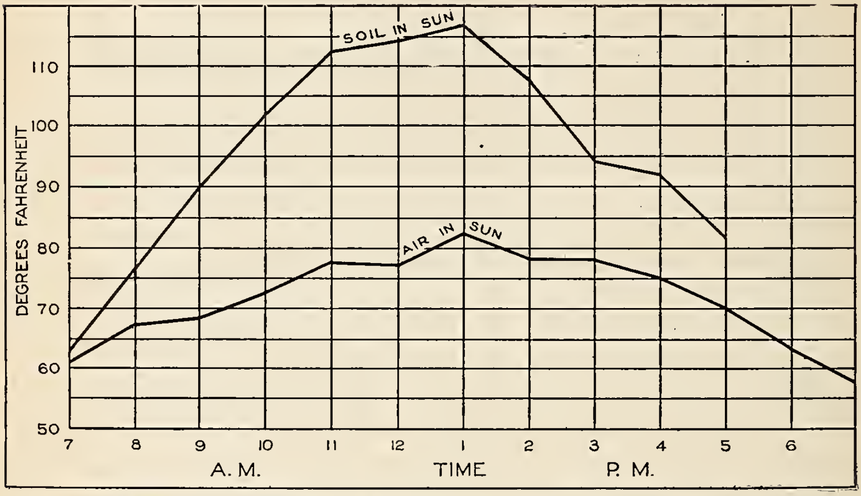

FIG. 16.—Diagram showing hourly temperature of air in sun and soil in sun, September 29, 1905, in an orange orchard at Arlington Heights, Riverside, Cal.

The same fact is shown somewhat more fully and for a longer period in figure 17. The figures from which this diagram was made were obtained by taking a mean of the morning, noon, and evening records

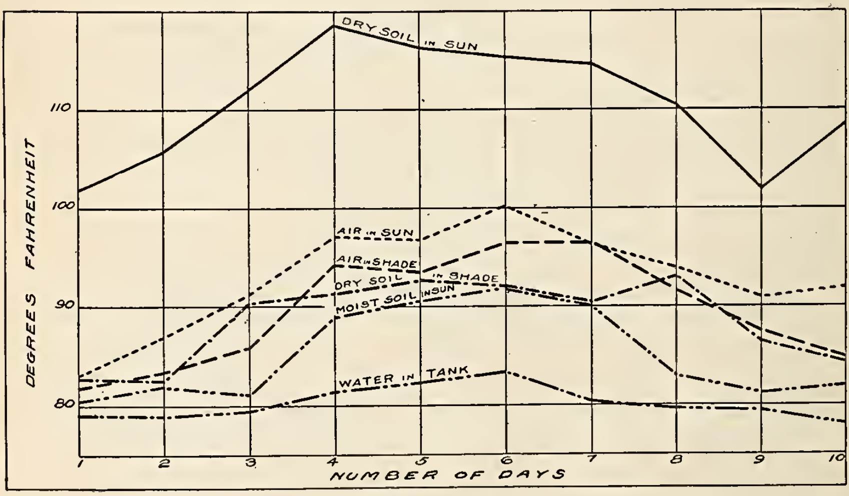

FIG. 17.—Average daily temperature for ten consecutive days.

of each day for ten consecutive days, beginning August 24, 1905. The time of taking these records was usually 8 a. m., 12 m., and 5 p. m. This diagram also enables one to compare the average day temperature of the air with that of shaded soil and the surface of water confined in the evaporation tank. All of the records were taken on one of the orange orchard tracts at Arlington Heights.

Similar data are given in figure 18, which represents the mean temperature records taken each day in the same orchard while the sun was shining for a period of nine consecutive weeks, beginning June 30, 1905.

The diagrams (figs. 16 to 18) show perhaps better than words can express the high temperatures reached by the surface of dry soil when exposed to the rays of the sun in midsummer. The experiments on evaporation from a water surface show that it varies in amount with the temperature of the water. Assuming that the same law is relatively true for soils, the evaporation must be excessive when the temperature of dry soils is over 100° and that of moist soils from 80° to 90°. These results show that from the standpoint of economy in water the best time to irrigate is during the night rather than the day. There are, of course, practical reasons which would prevent the general adoption of this rule. Water is delivered continuously from canals, and the users are forced to take their supply when it is available, whether day or night. The present method in most localities is to attend to the irrigation stream during the daytime and to permit it to flow over a field during the nighttime without attention. In this practise a change is desirable. Less water would be wasted and better results obtained if the irrigator rested during the hot hours of midday and worked far into the night. Lawns are now irrigated almost wholly in the evening. The same practise might

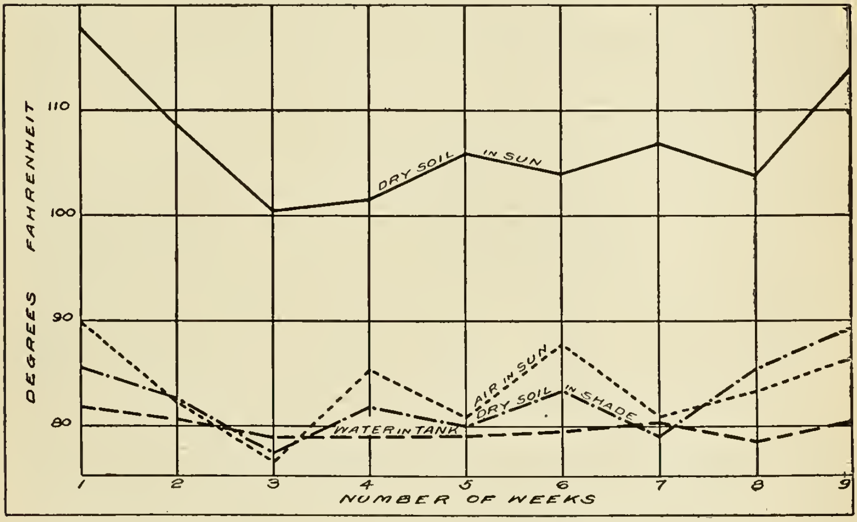

FIG. 18.—Average weekly temperatures for nine consecutive weeks.

be extended to truck gardens and small orchards with equally good results.

EFFECT OF SHADE AND SHELTER ON EVAPORATION.

It is well known that when crops cover the ground there is much less water evaporated from the surface of the soil. This is mainly due to three causes. In the first place, the plants prevent in whole or in part the crusting over of the surface; secondly, the shade created by them lowers the temperature; and lastly, the free movement of the wind is checked. The first of these causes pertains to cultivation and need not be discust, but some knowledge of the effect produced by shade may be gained from the temperature records previously given. The following table gives the daily temperature records of soil in the sun and soil in the shade, taken at 1 p. m. each day at Arlington Heights, Riverside, Cal., from August 24 to September 2, 1905:

Temperature at Arlington Heights, August 24 to September 2, 1905.

Date.	Temperature of dry soil in sun.	Temperature of dry soil in shade.	Date.	Temperature of dry soil in sun.	Temperature of dry soil in shade.
	°F.	°F.		°F.	°F.
August 24	130	91	August 29	135	102
25	126	93½	30	140	103½
26	138½	101½	31	132	101½
27	143	100	September 1	136	97½
28	141½	106½	2	130	96

As regards the effect of wind on evaporation, observations were made at Berkeley in 1904 and at Tulare, Chico, and Lone Pine in 1905. At each of the four stations at least one tank was sheltered from the wind, and the difference between the evaporation from the exposed and sheltered tanks was noted. At Berkeley two tanks were sheltered, the shelter being a tight board fence 7 feet high surrounding the tanks in a triangle. At Tulare and Chico a square canvas shelter 6 feet high was used. At Soldiers' Camp, near Lone Pine, the canvas was stretched against the prevailing southeast wind in such a way as to nearly cut off the direct air current, altho ordinary circulation was not interfered with. A standard anemometer set 18 inches above the ground and connected with an electric recording instrument in the observer's tent 100 feet away gave the wind velocities. The results for the four stations are in the summary following:

Summary of observations on influence of wind on evaporation from water surfaces.

Place.	Date.	Exposed to wind.		Shielded from wind.		Average velocity of wind per hour.	Average increase in daily evaporation per mile of wind movement.	
		Average temperature water surface.	Average daily evaporation.	Average temperature water surface.	Average daily evaporation.			
		°F.	*Inch.*	*°F.*	*Inch.*	*Miles.*	*Inch.*	*Per ct.*
Berkeley	Aug. 5-20, 1904	63.9	0.20	66.5	0.14	2.87	0.0009	0.65
Do	do	64.0	.21	67.0	.13	2.87	.0011	.83
Tulare	June 12-26, 1905	76.2	.40	77.2	.32	2.4	.0014	.43
Chico	July 8-23, 1905	79.4	.40	79.2	.38	2.84	.0003	.07
Soldiers' Camp near Lone Pine	Aug. 2-13, 1905	67.2	.43	66.2	.33	4.0	.0011	.32
Means							.0010	.46

The mean of the four series of observations indicates an increase in the daily evaporation of 0.46 per cent for each mile of wind movement. While the mean temperatures of the water surfaces in the exposed and sheltered tanks were not always the same, the departures were so small that corrections seem unnecessary, considering that undue refinement was not attempted in conducting the experiments. Both the mean and individual results, notably that in Chico, where the large discrepancy indicates the probability of error in observation, are below the results obtained by Fitz-Gerald in his well-known Boston tests, and by Carpenter[a] in his tests. Both Fitz-Gerald and Carpenter found increases of about 2 per cent for each mile of wind movement. These results indicate the possibility of reducing evaporation losses considerably by the use of wind-breaks, altho in orchards this is not of great importance, since the trees themselves form a wind-break.

EVAPORATION FROM SOIL AND WATER SURFACES COMPARED.

In carrying on experiments to determine the evaporation losses from both bare and cropt soils the practise of the writer has been to record also the losses from a water surface during each experiment. The rate of evaporation from a water surface depends chiefly on the temperature of the water, the temperature and humidity of the surrounding air, and the velocity of the wind. These likewise influence the evaporation from soil surfaces, but in the case of the latter there is an additional factor which surpasses all others in its effect. This is the amount of moisture in the top layer of soil. Hence it follows that no reliable comparisons can be made between the evaporation from soil and water surfaces without taking this condition into consideration. In the summary which follows the tanks which held water and those which held soil were placed near each other, so that the influences exerted by wind, sunshine, temperature, and the condition of the atmosphere were the same for both. The following table includes the weekly rate of evaporation from a water surface and also from soil surfaces containing different percentages of free water under the conditions stated. The soil was a well-pulverized sandy loam taken from an orange orchard.

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[a] Colorado Sta. Bul. 45.

Evaporation from soil and water.

Kind of soil and percentage of free water.	Mean temperature taken morning, noon and evening in degrees Fahrenheit.					Weekly evaporation.	
	Air in shade.	Soil in shade.	Soil in sun.	Moist soil.	Surface of water.	Soil.	Water.
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*Inches.*	*Inches.*
Sandy loam—saturated	71	76	95	83	77	4.75	1.88
Sandy loam—17.5..............	76	78	106	....	80	1.33	1.94
Sandy loam—11.9..............	76	78	106	....	80	1.13	1.94
Sandy loam—8.9................	76	78	108	....	80	.88	1.94
Sandy loam—4.8................	76	78	108	....	80	.25	1.94

The table shows that the loss of water by evaporation from heavily irrigated orchard soils while the surface is quite wet may amount to over 4 inches per week, or double that from the surface of water similarly situated and 2 feet deep. The loss from soils containing sufficient moisture in the top layer to nourish a vigorous growth in orchards is about 1 inch per week, or one-half that from a water surface. Soils that are fairly dry on top lose about one-fourth inch per week.

EVAPORATION FROM BARE SOILS.

Under this heading are summarized the results of experiments on evaporation from bare soils made at different times during the past two years at Tulare, Pomona, and Chico, Cal. In every case water-jacketed tanks were used, the inner vessel being about 17 inches in diameter and 30 inches deep, and holding 300 to over 400 pounds of soil. In taking soil from a field and placing it in a tank each thin layer was lightly tamped in order to have the column of soil in the vessel correspond as nearly as practicable to a like column in the field.

EVAPORATION FROM TULARE SOILS.

The soils used in this experiment were obtained, with one exception, from the substation farm near Tulare, Cal., which was intentionally located where the soil is impregnated with considerable quantities of alkali. Three different grades of this soil were used in the experiment. Four tanks were filled with soil from the alkali spots on which crops could not be grown, and are designated as strong alkali soil. Four were filled with coarse, sandy soil, and ten with the soil which was excavated from the trench in which the tanks were placed. This last was designated sandy loam. The remaining four tanks were filled with dark loam from an adjoining farm. It contained a considerable amount of organic matter and little if any alkali.

After the initial weighings had been made on May 30, 1903, each was irrigated on the surface, the amount applied being equal to a depth of 2 inches. The amounts of water applied in depth over the surface at the frequent irrigations and the corresponding dates are given below.

Water applied to soil tanks

Date.	Inches.	Date.	Inches.	Date.	Inches.
May 30	2.00	Aug. 1	1.00	Oct. 24	0.50
June 6	2.00	15	1.00	Nov. 7	.50
13	1.00	29	1.00	21	.50
20	1.00	Sept. 12	1.00	Dec. 5	.50
July 4	.25	26	1.00		
18	.25	Oct. 10	.50	Total	14.00

The soil in some of the tanks of each group was not cultivated either before or after irrigation. In the remainder, the surface layer of soil was either cut with a shovel or overturned, but not pulverized, the day following each irrigation. In loosening the soil with a shovel, an attempt was made to imitate poor cultivation. No weeds were allowed to grow on any of the tanks.

The results of the experiments with twenty-two tanks, which lasted from May 30 to December 9, a period of six months and nine days, are summarized in the following table:

Evaporation from bare soils at Tulare, Cal.

Number of trials.	Depth over surface.			Loss by evaporation.		Remarks.
	Rainfall.	Irrigation.	Total.	Depth over surface.	Total water received.	
	Inches	*Inches.*	*Inches.*	*Inches.*	*Per cent.*	
Initial moisture			2.80			
2	0.42	14	14.42	12.9	75	Strong alkali soil, not cultivated.
2	.42	14	14.42	13.9	81	Strong alkali soil, poorly cultivated.
2	.42	14	14.42	15.0	87	Coarse sandy soil, not cultivated.
2	.42	14	14.42	12.6	73	Coarse sandy soil, poorly cultivated.
4	.42	14	14.42	12.6	73	Sandy loam, not cultivated.
6	.42	14	14.42	14.0	81	Sandy loam, poorly cultivated.
2	.42	14	14.42	15.9	92	Dark loam, not cultivated.
2	.42	14	14.42	15.6	91	Dark loam, poorly cultivated.
Mean			17.22	14.1	82	

The preceding table shows that in a region like the San Joaquin Valley in California, where the temperature in summer is high and the evaporation excessive, small amounts of water applied to the surface at frequent intervals and without being followed by thoro cultivation are of little value. According to the table, 82 per cent of all the free moisture in the soil was evaporated from the surface of bare soil, which equaled 98 per cent of that received from irrigation and rainfall.

Another point which should be emphasized is the fact that imperfect cultivation is of little benefit in checking evaporation, the average percentage of loss for the two being exactly equal in this experiment. The surface layer should be well pulverized—a mere loosening of the soil will not suffice. In this connection it is well to keep in mind the fact that the soils used in the experiment were for the most part impregnated with alkali, and that such soil is difficult to cultivate and does not make an effective mulch. Then again, if a crop had been grown on this irrigated soil, the plants would have received a portion of the irrigation water before it had a chance to escape into the air by surface evaporation.

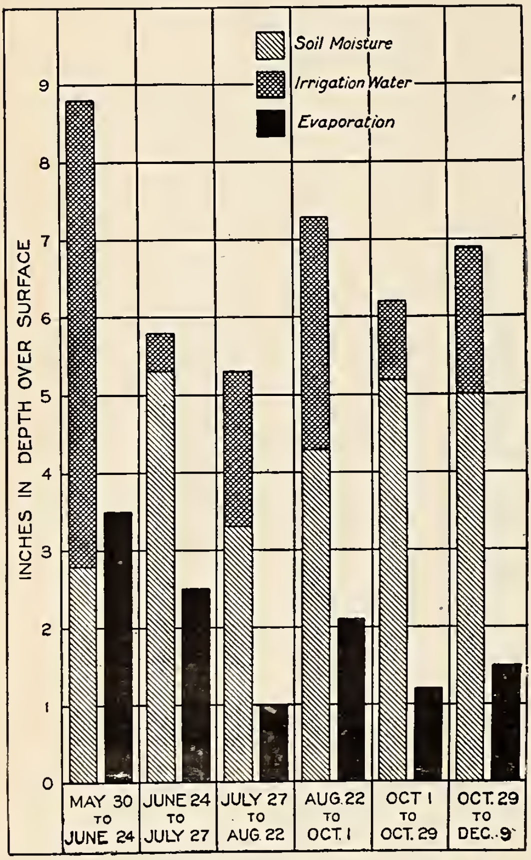

FIG. 19.—Diagram showing relation each month between evaporation and water in the soil.

Figure 19 shows the average monthly losses by evaporation from the twenty-two tanks, as well as the amount of water applied each month and the average moisture content of the soil.

EVAPORATION FROM POMONA SOILS.

On June 20, 1903, three tanks were filled with sandy loam taken from a trench in a corner of the substation farm near Pomona, Cal. The surface soil was irrigated once a month by applying 2 inches of water in depth over the surface, and one or two days afterwards it was cultivated to a depth of a few inches. A little rain fell in both August and September. The monthly losses by evaporation as well as the total loss from June 20 to October 24, a period of four months and four days, are given in the following table:

Evaporation from surface of bare soils at Pomona, June 20 to October 24, 1903.

Tank No.	Initial weight.	Water added.				Loss by evaporation.						
		June 20 to July 24.	July 24 to Aug. 24.	Aug. 24 to Sept. 28.	Sept. 28 to Oct. 24.	June 20 to July 24.	July 24 to Aug. 24.	Aug. 24 to Sept. 28.	Sept. 28 to Oct. 24.	Total.		Per cent.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*In.*	
8	3,565	16.00	16.00	17.92	16.32	12.75	18.25	17.80	13.50	62.30	7.60	94
9	3,735	16.00	16.00	17.92	16.32	14.25	16.75	15.80	15.00	61.80	7.54	93
10	3,575	16.00	16.00	17.92	16.32	14.50	16.75	16.05	14.20	61.50	7.50	93

EVAPORATION FROM ORCHARD SOILS.

In the spring of 1904 soils were shipped from Fullerton, Redlands, and Riverside, Cal., to the substation near Pomona for experimental purposes. The Fullerton soil was a heavy dark loam, typical of much of the best walnut lands of Orange County; that from Riverside was a sandy loam from an orange grove, and that from Redlands was a retentive red clay, also from an orange orchard. Each of these soils was placed in separate tanks and installed beside two tanks of Pomona soil, all being quite dry at the time, and the loss by evaporation determined. The amounts of both rainfall and irrigation water which were added to the tanks each month, as well as the corresponding losses, are given in the following table:

Loss by evaporation from orchard soils at Pomona, February 23 to August 31, 1904.

WATER ADDED.

Tank No.	Initial weight.	Feb. 23 to Apr. 30.	Apr. 30 to May 31.	May 31 to June 30.	June 30 to July 26.	July 26 to Aug. 31.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
4 [a]	345.0	54.8	17.44	16.00	16.00	1.52
9–10 [b]	375.5	54.8	17.44	16.00	16.00	1.52
C [c]	449.0	54.8	17.44	16.00	16.00	1.52
F [d]	430.0	54.8	17.44	16.00	16.00	1.52

LOSS BY EVAPORATION.

Tank No.	Initial weight.	Feb. 23 to Apr. 30	Apr. 30 to May 31.	May 31 to June 30.	June 30 to July 26.	July 26 to Aug. 31.	Total.		Per cent.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	
4 [a]	345.0	50.20	9.50	9.25	13.00	10.35	92.30	11.25	87
9–10 [b]	375.5	68.83	12.00	14.50	15.25	11.22	121.80	14.85	115
C [c]	449.0	61.45	7.75	11.00	12.50	3.10	95.80	11.68	91
F [d]	430.0	42.20	13.50	11.00	15.00	7.85	89.55	10.92	85
Average									94

[a] Fullerton soil. [b] Pomona soil. [c] Redlands soil. [d] Riverside soil.

The evaporation losses from the same types of soils at Pomona from September 1 to December 14, 1904, together with the amount of water received in both rainfall and irrigation, are given in the following table:

Loss by evaporation from surface of orchard soils at Pomona from September 1 to December 14, 1904.

Tank No.	Initial weight.	Water added.				Loss by evaporation.				Total.		Per cent.
		Sept. 1 to Oct. 1.	Oct. 1 to Nov. 1.	Nov. 1 to Dec. 1.	Dec. 1 to Dec. 14	Sept. 1 to Oct. 1.	Oct. 1 to Nov. 1.	Nov. 1 to Dec. 1.	Dec. 1 to Dec. 14			
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*In.*	
4[a]	317.00	8.00	11.92	8.00	8.00	10.75	11.85	7.50	6.00	36.10	4.40	100
9-10[b]	345.75	8.00	11.92	8.00	8.00	9.50	12.35	7.75	5.13	34.73	4.24	97
C[c]	344.75	....	11.92	8.00	8.00	4.00	13.35	7.75	8.65	33.75	4.12	121
F[d]	345.75	....	11.92	8.00	8.00	4.25	14.10	7.00	7.90	33.25	4.05	116

[a] Fullerton soil. [b] Pomona soil. [c] Redlands soil. [d] Riverside soil.

EVAPORATION FROM CHICO SOILS.

On February 9, 1905, an experiment was begun near Chico, Cal., to determine the probable loss of water by evaporation from plowed fields during the spring months. Six double water-jacketed tanks were filled with dark loam taken from the plant introduction garden farm of the United States Department of Agriculture, located near Chico. The soil was quite moist when placed in the tanks, containing on an average 17.3 per cent of free moisture. No irrigation water was applied, since the rainfall of February, March, and April, amounting to 9.12 inches, was sufficient to keep the soil continuously moist. No weeds were allowed to grow, but the surface was not cultivated. The experiment, which lasted from February 9 to May 9, 1905, a period of three months, was conducted by Prof. P. H. Dorsett, in charge of the plant introduction garden. The rainfall and evaporation losses for each month are given in the following table:

Loss by evaporation from surface of bare soils at Chico, Cal., February 9 to May 9, 1905.

Tank No.	Initial weight.	Rainfall.			Rainfall.			Loss by evaporation.					Per cent.
		Feb.	Mar.	Apr.	Feb.	Mar.	Apr.	Feb.	Mar.	Apr.	Total.		
	Lbs.	*In.*	*In.*	*In.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*In.*	
1	367	1.52	4.29	3.31	12.6	35.8	27.6	9.6	15.8	22.6	48.0	5.76	63
2	367	1.52	4.29	3.31	12.6	35.8	27.6	8.6	15.8	22.6	47.0	5.64	62
3	367	1.52	4.29	3.31	12.6	35.8	27.6	8.6	19.8	22.1	50.5	6.06	66
5	367	1.52	4.29	3.31	12.6	35.8	27.6	9.6	17.8	20.6	48.0	5.76	63
6	367	1.52	4.29	3.31	12.6	35.8	27.6	10.6	17.8	20.6	49.0	5.88	64
Average	....	....	....	....	....	....	....	....	....	....	....	....	63

The conclusions which may be drawn from a study of the preceding tables are briefly stated as follows:

(1) The evaporation losses from plowed but uncropt soils in the

warmer valleys of California may exceed nine-tenths of the water applied to the surface in small amounts at frequent intervals, and without being followed by thoro cultivation.

(2) The stirring or overturning of surface soil which is not well pulverized may increase rather than decrease the loss by evaporation.

(3) The character of the soil does not appear to exert much influence in the rate of evaporation.

(4) On the plowed but uncropt farms of the Sacramento Valley in California, the loss from evaporation from February 9 to May 9, 1905, was equivalent to a depth of 5 inches over the surface.

WATER REQUIREMENTS OF CROPS.

In planning experiments to determine the evaporation losses from bare soils under different conditions it was thought advisable to use part of the equipment during certain periods for the raising of crops within water-jacketed tanks. The purpose of experimenting with some of the staple crops was threefold: (1) To ascertain some of the effects of applying different amounts of water on the growth and yield of plants; (2) to determine the amount of water evaporated from both plants and soil under given conditions, and (3) to ascertain the difference between the amount evaporated by the soil and that transpired from the foliage of plants. The first and second of the objects named presented no serious difficulties, but in the case of the third no practical means could be adopted that would maintain alike all the conditions which influence evaporation in both the bare and cropt soils within the tanks. Such climatic conditions as wind, sunshine, rain, and temperature could be made and were made practically the same in both while the plants were young, but with maturer growth differences caused by the shading and protection of the soil could not be prevented.

In each experiment evaporation from bare tanks was measured, but the cropt tanks received different quantities of water. The experiments previously reported show that the quantity of water in the soil has a greater influence on evaporation than any other factor, and it can not be assumed that the difference between the quantities lost from the bare soil and from the cropt tanks represents the quantities consumed by the plants. The experiments are, therefore, chiefly valuable as showing the crop yields from similar tanks receiving different quantities of water. The results are summarized under the various experiments.

WHEAT EXPERIMENT NO. 1, AT TULARE.

The first experiment with wheat was begun at Tulare December 11, 1903. Nine water-jacketed tanks, 12 inches in diameter and 29 inches deep, were used, the soil with which they were filled being a rich black loam from the Foster farm, 1 mile southeast of the Tulare substation. For twenty years this soil had been raising barley, with the exception of 1903, when, after summer fallowing, 14 sacks, or 33 bushels, of wheat were raised per acre. Tanks 1 to 7 were seeded to White Australian wheat on the day the experiment was begun, but tanks 19 and 20 were left bare for determining merely the loss by evaporation. The tanks were all weighed on December 11, again on February 10, and monthly thereafter until the close of the experiment. Owing to the cold, foggy days of the winter but little loss occurred during the first two months, and on February 10 only a few blades of grain had come up. On March 12 it was 3 to 7 inches high, but thinner than might have been desired. On April 12 it was 8 to 10 inches high and showed little injury from the preceding dry, hot weather. Irrigation was begun on that date. It was arranged that tanks 1 and 2 should be left without water; that tank 3 should receive 4 inches immediately, but no more; and that tanks 4 to 7 should receive several waterings of 4 inches each. This schedule was later slightly changed, and by June 14, when the crop was harvested, tank 4 had received 8 inches, exclusive of the rainfall of 6.28 inches; tank 5, 12 inches, and tanks 6 and 7, each 16 inches. After the crop was harvested, it was found that the soil in all of the tanks was dry, No. 7 being badly caked, and Nos. 1 and 2 dry and dusty on top—apparently not greatly different from when placed in the tank on December 9, 1903.

The yields from the various tanks, together with the amount of water received and the net loss in weight during the season, are given in the following summary:

Yields of wheat, total water received, and water lost by evaporation and transpired and used by crop in Tulare wheat experiment, 1903–4.

Numbers of tanks.	Total water received.	Total net loss during season.	Yield of grain.
	Pounds.	*Pounds.*	*Grams.*
1 and 2	57.27	79.77	0.0
3	93.75	113.75	10.0
4	128.49	147.49	14.0
5	161.49	186.49	19.0
6 and 7	199.71	216.71	38.0
19 and 20 [a]	75.51	69.76	

[a] Bare soil.

Altho it was intended that tanks 6 and 7 should receive sufficient water to reduce the yield, this result was not obtained. So far as yield is concerned, the experiment seems merely to show that, up to a certain point at least, an increase in the quantity of water applied increases the yield.

WHEAT EXPERIMENT NO. 2, AT TULARE.

This experiment was a repetition of the first wheat experiment at Tulare, with such alterations as the different seasons demanded and the first experiment suggested. Tanks 1 to 7 and 21 were used, numbers 1 and 21 being bare, and the remainder being seeded on January 12, 1905, to California spring wheat from the substation at Tulare. The soil used in the previous experiment—a 10-inch subsoil of worn-out grain soil covered with 20 inches of black loam—was retained for this experiment, and it contained at the time of seeding 15.52 per cent of free moisture. This experiment and a simultaneous barley experiment were the first in which the aim to give some tanks sufficient water to clearly retard growth and reduce the yield was realized.

The spring of 1905 was a backward one thruout San Joaquin Valley, rainfall and fogs greatly holding back all crops. However, on March 15 the growth was thrifty, the wheat being about 10 inches high. On May 3 the crops in tanks 2 and 3, which by the schedule were to receive no water, were drying up, not having grown any since April 13. On the same date tanks 6 and 7, which it was intended should receive too much water, were saturated and the wheat in them was turning yellow. The crop in tanks 4 and 5, however, which were to receive as nearly as practicable the amount needed for the most satisfactory growth, were in good condition. The experiment was terminated on June 22, when the final weights were taken and the crop harvested.

On March 15, when it became necessary to begin irrigation, a definite schedule of applying water was arranged, by which tanks 2 and 3 were to receive no water, tanks 4 and 5 were to receive a depth of 2 inches, and tanks 6 and 7 a depth of 4 inches for at least three more waterings. On April 13 the amount for each watering was changed to 3 inches in depth for tanks 4 and 5 and to 5 inches for tanks 6 and 7. The total amount of water finally applied was, in addition to the rainfall of 8.07 inches, 4 inches for tanks 2 and 3, 10 inches for tanks 4 and 5, and 19 inches for tanks 6 and 7. Bare tanks 1 and 21 each received an average of 2.62 inches in depth.

The difference in yield in the various tanks is shown in the table below. In this table the yields from the tanks receiving the same quantities of water are averaged.

Yields of wheat in tanks 2 to 7, at Tulare, January 11 to June 22, 1905, with amounts of water received.

Numbers of tanks.	Total water received.		Loss.	Yield of grain.
	Pounds.	*Inches.*	*Pounds.*	*Grams.*
2 and 3	110.08	12.07	136.58	11.2
4 and 5	164.80	18.07	190.30	33.6
6 and 7	246.88	27.07	254.68	16.6
1 and 21	[a]97.53	10.69	92.60	....

[a] Bare soil.

From the above it would seem that a total depth of 27.07 inches of water is more than wheat can use to advantage under climatic conditions similar to those which obtained during this experiment. The reduction of 50 per cent in the yield by the application to tanks 6 and 7 of 9 inches more than tanks 4 and 5 received is conclusive as to this. This does not necessarily mean, however, that the same result would follow under field conditions, because, as has been repeatedly pointed out, no water is lost from the tanks by percolation beyond the reach of the crop.

BARLEY EXPERIMENT NO. 1, AT TULARE.

This experiment, the first in which barley was the crop used, was begun December 11, 1903, simultaneously with the first wheat experiment. The purpose was to determine the effect of varying the amount of water applied to barley growing in sandy loam that had been cropped to grain continuously for twelve or fifteen years, yielding an average of 800 pounds per acre. Nine water-jacketed tanks numbered 17 and 18 and from 21 to 27, were used, all being 17 inches in diameter and 29 inches deep. The soil was placed in the tanks as nearly as possible in its natural condition, which was 4 or 5 inches on the surface of partly pulverized soil, underlaid with a plow sole of the same material extending 10 to 14 inches below the surface, which was in turn underlaid with a fairly moist reddish sand, with a little loam intermixt. On February 10 but little growth had occurred, but by March 12 it was vigorous, the grain being 5 to 10 inches high. On April 12 the grain was quite uniform in the tanks and beginning to head out. It was, however, showing the effects of the recent dry weather, no water having yet been applied. On this date 4 inches in depth was applied to all but bare tanks 17 and 18 and cropped tanks 21 and 22, the intention being to leave the two latter without water thruout the season. No more water was applied to tank 23, but No. 24 received 4 more inches in depth during the remainder of the season; No. 25, 8 inches; and Nos. 26 and 27, 12 inches. On May 11 tanks 21 and 22, which received no water, hardly had sufficient growth to make a stand. The others on the same date were better in appearance in about the proportion that they had received more water. The soil in all, however, was abnormally dry, and only in the three tanks which had received the most water was the grain normally headed and filled out.

When the experiment was terminated and the soil turned out of the tanks, that in Nos. 21 and 22, which received no irrigation water, was very dry. Roots had accumulated in the bottom of the tanks in their search for what moisture the soil contained. The bare tanks, 17 and 18, were fairly moist up to within 4 to 6 inches of the surface.

In Nos. 26 and 27, which received the most water—16 inches in addition to rainfall—the surface was dry, but the bottom layers were quite moist

All the tanks were weighed on December 11, when the experiment was begun, again on February 10, and monthly thereafter. This makes it possible to show the seasonal net losses in weight from evaporation and the use and transpiration of water by the crop. These losses, as well as the total amounts of water received by each tank and the yields of grain, are given in the following summary:

Yields of barley, total water received, and loss by evaporation and amount of water transpired and used by crop in Tulare barley experiment, 1903–4.

Numbers of tanks.	Total water received.	Total net loss during season.	Yield of grain.
	Pounds.	*Pounds.*	*Grams.*
21 and 22	57.27	78.27	27
23	93.75	107.75	41
24	128.49	148.49	62
25	161.49	170.49	48
26 and 27	198.71	198.96	66
17 and 18	75.51	78.01	....

This experiment proved of little value, except to show the total quantities of water lost, since the yields do not follow any rule with relation to the quantities of water applied. But if the results from tank 25, in which the yield was below that in the next preceding tank, which received less water, be thrown out, there is found to be a slight increase in yield with the different amounts of water applied and with the different amounts that were used by the crops. In other words, up to the limits of the experiment there was a steady increase in the yields and in the amounts of water used by the plant with the increase in the amount of water applied.

BARLEY EXPERIMENT NO. 2, AT TULARE.

When the second experiment with wheat was begun at Tulare, on January 11, 1905, a second experiment was also begun with barley. Tanks 14, 16 to 20, and 1 to 21 were used, the two latter being the bare tanks also referred to in connection with the second wheat experiment. The soil of the previous experiment was retained for this one, containing at the start 15.52 per cent of free moisture.

On January 11 tanks 14 and 16 to 20 were seeded, the barley used being numbered 7969 on the substation record. On March 15 the stand had reached an average height of about 12 inches and was thrifty. Thus far a depth of 4 inches of irrigation water had been given. By April 13, altho still thrifty, the crop had begun to show a need for water, and part of it was beginning to head, the average height being about 24 inches. On May 27 the crop was harvested and the experiment terminated. Counting rainfall of 8.07 inches, the total depth of water received had been 10.69 inches for bare tanks 1 and 21, 12.07 inches for tanks 19 and 20, 18.07 inches for tanks 17 and 18, and 27.07 inches for tanks 14 and 16.

The difference in yield in the various tanks is shown in the table below. In this table the yields from the tanks receiving the same quantities of water are averaged.

Yields of barley in tanks at Tulare, Cal., January 11 to May 27, 1905, with amounts of water used and lost.

Number of tanks.	Total water reeceivd.		Loss.	Yield of grain.
	Pounds.	*Inches.*	*Pounds.*	*Grams.*
19 and 20	110.08	12.07	130.0	85.7
17 and 18	164.80	18.07	157.3	139.2
14 and 16	246.88	27.07	194.7	60.0
1 and 21	97.53	....	92.6	....

The above table shows that while a depth of 18.07 inches of water gave a large increase in yield over a depth of 12.07, a depth of 27.07 inches not only reduced the yield below that from the tanks receiving 18.07 inches, but also below that from the tanks receiving only 12.07 inches. The evils of overirrigation without proper drainage are therefore plain.

HORSE-BEAN EXPERIMENTS, BERKELEY.

The purpose of this experiment was to determine the effect of applying different amounts of water to the common Portuguese or horse bean (*Vicia faba*) raised during the late fall and winter. This bean is grown quite largely for commercial use in some of the market-garden districts surrounding San Francisco Bay, and at the time of the experiment the California Agricultural Experiment Station was raising it at some of the substations with a view to determining its value as a green-manuring plant. The equipment used consisted of seven water-jacketed tanks 17 inches in diameter and 29 inches deep. These tanks were filled two-thirds full with a clayey soil. For the remainder of the depth a virgin clayey loam, slightly enriched with cow-barn manure, was used. The free-moisture content averaged 8.7 per cent.

The seed was planted in six of the tanks on September 1, 1904, the other tank being left bare. Eight beans, in four hills of two beans each, were placed in each of the six tanks. On the same date the initial weights of the tanks were taken.

When the experiment was begun it was proposed that two tanks should receive no water except rainfall, that two should be given such an amount as would give best results—believed to be a depth of about 6 inches in addition to the usual fall and winter rain—and that the remaining two containing beans should receive an excessive amount, probably a depth of 12 inches or more. With the exception of a depth of 1 inch of water applied within a week after planting, made desirable by excessively hot weather immediately following planting, this plan was followed so far as irrigation was concerned. The rainfall for the winter, however, was abnormal, 19.10 inches falling between September 22 and February 6, when the experiment was terminated. The result was a smaller difference in the total amounts of water received by the tanks than was intended, and consequently a smaller difference in the yields. The total amounts received by the six tanks were, including the rainfall of 19.10 inches, 20.10 inches for tanks 1 and 2, 24.10 inches for tanks 3 and 4, and 32.85 inches and 34.10 inches, respectively, for tanks 5 and 6. Altho tank No. 7, which was bare, received only 1 inch of irrigation water, the heavy rains kept it saturated thruout the term of the experiment, and at various times sufficient standing water was removed from the surface to make a total depth so removed for the season of 9 inches. At one time, before the plants had made much growth, it was also necessary to remove about 2 inches each from the four irrigated tanks. This excessive moisture showed plainly in the plants, all turning a yellowish color and being far less thrifty in appearance than those in the two unirrigated tanks, Nos. 1 and 2. When all of the plants became larger, however, the conditions were reversed, the unirrigated plants falling behind and the irrigated plants quickly using up any excess of moisture that accumulated from rainfall or overirrigation. On December 8 the plants in the unirrigated tanks were badly wilted and those in tanks 3 and 4 beginning to wilt, altho, including rainfall, they had received, respectively, 10.88 and 13.88 inches of water. Altho the 0.21 inch of rainfall of the next five days revived them somewhat, they were again wilting on December 16, and also blossoming. Meanwhile, the plants in 5 and 6, which had received a total of 22.88 inches of water, were still thrifty and growing, showing that the greater amount of water was none too much under the conditions present. None of the tanks was cultivated after October 1.

The experiment was terminated on February 6, 1905, the final weighing being made on that date. Altho all of the plants had blossomed, none set fruit. When cut, those in tanks 1 and 2, which received in all 20.10 inches of water, averaged 3 feet 6 inches in height; those in tanks 3 and 4, which received 24.10 inches, averaged 4 feet 2 inches; and those in tanks 5 and 6, which received respectively 32.85 and 34.10 inches, averaged 4 feet 11 inches.

As no beans were produced, the relative yields were determined by weighing the green stalks. The average weight of these stalks in tanks 1 and 2 was 3,352 grams; in tanks 3 and 4, 4,281 grams: and in tanks 5 and 6, 4.547 grams. In other words tanks 3 and 4, with 20 per cent more water than tanks 1 and 2, produced 28 per cent more green matter; but tanks 5 and 6, which received 70 per cent more water than tanks 1 and 2, produced only 36 per cent more green matter.

This experiment made it plain that the horse bean requires a large amount of water, also it shows that the returns from applying water diminished after a certain point was reached. The plants should have been continued in growth to the point of producing seed, if irrigation had been continued. Without further irrigation, however, nothing could have been expected, as the supply of moisture in the comparatively small amount of soil inclosed in the tanks was plainly inadequate. It is interesting to add that the same crop, grown in nearby plats, by the California Agricultural Experiment Station, from October 22, 1904, to July 21, 1905, yielded at the rate of 1,650 pounds of seed per acre and reached a height of 6 feet.

The first experiment with the horse bean was terminated prior to fruiting to make way for a second experiment with the same crop, to be carried on during the spring and summer rather than during the fall and winter. The second crop was planted March 8, using the same soil as in the first experiment, but containing at the start only 5.8 per cent of free moisture. As in the first experiment, eight beans were planted in each tank. Between March 8 and August 8, when the experiment was terminated, the rainfall was 9.73 inches. In addition to this, tanks 1 and 2 received 1 inch of water, tanks 3 and 4, 17 inches, and tanks 5 and 6, 29.5 and 28 inches, respectively, the two latter tanks receiving these amounts in nine irrigations, between March 8 and July 13. On May 8 recent rains made it necessary to remove small amounts of standing water from tanks 5 and 6, the soil in them being saturated and the plants beginning to turn yellowish similarly to the plants in some of the tanks during the first experiment. Otherwise, on this date the plants all showed vigorous growth, and all stood about 2 feet high, with a few blossoms appearing. On May 18 the plants in tanks 5 and 6 were clearly losing ground from an excess of water, which was in direct line with the intent of the experiment, the idea being, as in the first experiment, to give two tanks too little water and two tanks too much. On June 6, however, the plants in tanks 1 and 4 were badly wilted and those in tanks 5 and 6 showed the most vigorous condition. Further irrigation was given tanks 5 and 6, with the idea still in mind to give tanks 5 and 6 an excess. While the soil in tanks 5 and 6 was kept nearly saturated much of the time, the plants had reached a stage where they seemed able to use, either beneficially or otherwise, all the water they could get. On June 27, the plants in tanks 1 and 2 were completely wilted and dried up, those in tanks 3 and 4 were again beginning to show a need for more water, while the plants in tanks 5 and 6 were still growing and blossoming. The last waterings were given July 13, prior to which the plants in the four remaining growing tanks were wilting. Nothing further was done with the crops, except to photograph them on July 24, and to take the final weights on August 8, weights having been taken monthly, as in the first experiment.

Because the plants of the second experiment were left standing until the seed matured, it was not possible to directly take the green weights for comparison with the first experiment. However, the dry weights were taken and the green weights estimated therefrom.

The total amount of water received by tanks 1 and 2 in the second experiment was 10.73 inches. The yield in green matter was an average of 404 grams each. Tanks 3 and 4 each received 26.73 inches of water and yielded an average of 1,386 grams. Tanks 5 and 6 each received an average of 38.48 inches and yielded an average of 2,095 grams. The excess of water received by tanks 3 and 4 over tanks 1 and 2 was 149 per cent, and the excess of yield was 243 per cent. Tanks 5 and 6 received 258 per cent more water than tanks 1 and 2 and yielded 418 per cent more green matter. The yields in beans were, none for tanks 1 and 2, 77 grams each for tanks 3 and 4, and 92 grams each for tanks 5 and 6.

The second experiment, as the first, showed that, because of its heavy foliage and its consequent large transpiration surface, the horse bean uses a large amount of water. As already indicated, the transpiration was at several periods greater than the amounts applied in irrigation. This deficiency was made up from the initial moisture in the soil. This is plain by a comparison of the amounts of water received with the amounts transpired by the plants and evaporated from the soil. In the summary below giving these comparisons the amounts of water applied to and evaporated from uncropt tanks and the yield from the cropt tanks are included.

Comparison of amounts of water applied to horse beans, with the amounts lost by evaporation and transpired by the plants.

Numbers of tanks.	First experiment.			Second experiment.		
	Total water received.	Total net loss during experiment.	Yield of green matter.	Total water received.	Total net loss during experiment.	Yield of green matter.
	Pounds.	*Pounds.*	*Grams.*	*Pounds.*	*Pounds.*	*Grams.*
1 and 2	167.50	132.87	3,352	89.60	113.72	404
3 and 4	199.85	155.22	4,281	223.20	240.57	1,386
5 and 6	276.25	240.50	4,547	321.81	316.31	2,095
7	92.00	42.25	....	131.35	95.85	....

This summary shows, for instance, that in the first experiment 240½ pounds of water was required to produce the 4,547 grams of green matter harvested from each of tanks 5 and 6, and that in the second experiment 316.31 pounds of water was required to produce 2,095 grams of green matter taken from the same tanks. In the one case this was equal to a depth over the surface of 28.8 inches, and in the other of 37.8 inches. How much of the water was actually used by the plants and how much was lost by evaporation from the soil can not be stated positively. While bare soil tanks were run in each experiment, and the net loss by evaporation for the season determined, there is no assurance that in the crop tanks all above that amount actually entered into the life processes of the plant. No effort was made to keep the moisture content of the bare soil equal to that of the crop soil, and consequently the rate of evaporation was not the same. Also, the cropt soil was shaded by the plants while the bare soil was wholly exposed to the sun. However, assuming that the figures obtained are approximately accurate, some 200 pounds, or 24 inches, was used by the plants in tanks 5 and 6 in the first experiment, and some 220 pounds, or 26 inches, in the second experiment.

The results in the tanks as to the actual amount of water used are only partially adaptable to field conditions, because the amount of seed planted in the tanks was below the amount that would be planted in the field. In the tanks with a surface area of 1.58 square feet 8 beans were planted, or 5 per square foot. Under field conditions 8 to 12 per square foot would not be unusual perhaps, depending upon whether the crop is intended for seed or green manure.

CONCLUSIONS.

LOSS OF WATER BY EVAPORATION AND MEANS OF CHECKING IT.

The experiments reported in the preceding pages show that the conditions having the greatest influence on evaporation from soils are the quantity of water in the top soil, the temperature of the soil and water, and the wind movement. All of these can be controlled to a large extent by the irrigator by his methods of applying water and by subsequent cultivation of the soil. The application of the water in such a way as not to wet the top soil decreases the quantity of water in the top layer, and at the same time places the moisture in the soil beyond the influence of wind movements, and, to a considerable extent, beyond the influence of the high temperatures of unusually hot days. The daily variations in temperature almost disappear at a depth of 1 foot, the decrease in temperature from the surface down being very rapid on hot days. Records kept at the Nebraska Station show that during the month of July, 1889, the average difference in temperature at noon between the soil at depths of 1 and 3 inches was 8° F., while on the hottest days the difference was more than 15°.[a] The records at Riverside, Cal. (see p. 43), show an average difference in the temperature of dry soil in the sun and dry soil in the shade for ten consecutive days of 35° F. It is evident, therefore, that applying water at depths of 3 inches or more below the surface reduces greatly the temperature to which it is subjected. Cultivation after irrigation has the same effect, since loose earth is a poor conductor of heat. King found in an extreme case a difference of 10° in temperature at the depth of 1½ inches between adjacent soils, one of which was compacted and the other loose.[b] The table on page 42 shows an average surface temperature of over 134° F. at 1 p. m. for ten consecutive days. Against such extremes a loose soil mulch is a very effective protection.

The experiments did not include the measurement of evaporation losses from soils at different temperatures, but that from water surfaces kept at different temperatures was determined (see p. 45). Averaging the results from four stations: Decreasing the temperatures from 88.7° F. to 80.4° F. reduced evaporation 20 per cent; reducing it to 73.5° F. decreased evaporation 40 per cent; at 61.3° F. the decrease was 67 per cent, and at 53.4° F. it was 85 per cent. Expressing the results of these experiments in daily rate of evaporation, other conditions being equal, there is an average difference in the daily evaporation of 0.014 inch for each change of 1° in temperature. That is, about 7° reduction in temperature decreases evaporation from a water surface 0.1 inch per day. The amount evaporated from soils depends on the wetness of the soil, but the proportionate saving with reductions in temperature is probably as great as that from water surfaces.

This points to the possibilities of saving by applying water at night, when the surface soil is cool; by applying it at sufficient depths to keep it from coming in contact with the hot surface layer of soil, and by frequent cultivation to maintain a mulch of loose soil, which will prevent the excessive heat of summer reaching the moist soil, as well as destroying capillarity.

The following paragraphs give a quantitative statement of the saving of water by the various means just mentioned:

Cultivation after irrigation.—From soil which received sufficient water to cover it to a depth of 12 inches 1.65 inches were evaporated in the first five days after irrigation. At the end of that time half of it was cultivated. During the next six days the loss from the uncultivated soil was 1.38 inches, and from the cultivated soil 0.63 inch, the saving for the six days being 0.75 inch, or 6.25 per cent of the water applied. In a second experiment the depth applied was reduced to 8 inches, and the soil in one-half the tanks was cultivated at the end of three days. The loss for the first three days was 0.84 inch. During the next three days the loss from the uncultivated soil was 0.29 inch, and from the cultivated 0.1 inch, the difference in favor of cultivation being 0.19 inch, or 2.38 per cent of the amount applied.

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[a] Nebraska Sta. Rpt. 1890, pp. 26–27.

[b] Physics of Agriculture, p. 221.

Soil mulches.—From soil receiving water enough to cover it to a depth of 3.14 inches the losses in fourteen days were: With no mulch, 0.72 inch; with a 4-inch mulch, 0.21 inch; with an 8-inch mulch, 0.1 inch; and with a 10-inch mulch, 0.03 inch. Taking the loss with no mulch as a basis, the saving with the 4-inch mulch was 0.51 inch, or 16.24 per cent, of the amount applied; with the 8-inch mulch it was 0.62 inch, or 19.75 per cent, of the amount applied; and with the 10-inch mulch it was 0.69 inch, or 21.97 per cent, of the amount applied. These mulches were made by placing dry soil on top of the tanks after the water was applied, and the results are better than can be secured in field practice, as the top soil is always more or less wet when fields are watered, but they show that large savings can be made by maintaining soil mulches by cultivation.

Applying water in furrows.—From tanks receiving 5.19 inches of water the loss in ten days was 1.11 inches when water was applied to the surface; when it was applied in 3-inch furrows the loss was 0.99 inch; with 6-inch furrows, 0.94 inch; with 9-inch furrows, 0.82 inch; and with 12-inch furrows, 0.63 inch. Taking the loss from the surface application as a basis, as before, the savings were as follows: Three-inch furrows, 0.12 inch, or 2.31 per cent, of the amount applied; 6-inch furrows, 0.17 inch, or 3.28 per cent, of the amount applied; 9-inch furrows, 0.29 inch, or 5.59 per cent, of the amount applied; 12-inch furrows, 0.48 inch, or 9.23 per cent, of the amount applied. Other tanks in the same experiments received 4.9 inches of water. The loss when water was applied to the surface was 1.34 inches, and the saving when water was applied in the 3-inch furrows, 0.15 inch, or 3.06 per cent, of the water applied; in 6-inch furrows, 0.43 inch, or 8.77 per cent. In all these cases the soil was cultivated to a depth of 4 inches on the third day after the water was put on. In another experiment lasting thirty-five days the soil received 2 inches of water in 3-inch and in 12-inch furrows. The loss with the 3-inch furrows was 1.81 inches, and with the 12-inch furrows, 0.49 inch, the saving with the deeper furrows being 1.32 inches, or 66 per cent, of the amount applied. The last experiment is outside the limits of field practice, as such light irrigation at such long intervals is not practicable.

Subirrigation.—When 5.32 inches was applied in tubes at varying distances below the surface the losses in a ten-day period were as follows: Three inches below surface, 1.34 inches; 6 inches below the surface 0.96 inch; 9 inches below the surface, 0.55 inch, and 12 inches below the surface, 0.32 inch. On the basis of the loss with water applied at 3 inches the savings were 6 inches, 0.38 inch, or 7.14 per cent; 9 inches, 0.79 inch, or 14.85 per cent; 12 inches, 1.02 inches, or 19.17 per cent. In a second experiment water was applied to check tanks on the surface and to other tanks thru tubes 2 feet below the surface. With three different classes of soils the losses in twenty-six days were as follows: With sandy loam, receiving 7.02 inches of water, the loss from the surface-irrigated tanks was 4.22 inches, and from the subirrigated tanks 0.74 inch, the saving being 3.48 inches, or 49.57 per cent of the amount applied. With a sandy soil the loss from surface irrigation was 3.64 inches, and from subirrigation 0.62 inch, the saving being 3.02 inches, or 43.02 per cent of the amount applied. With a dark loam the loss from surface irrigation was 5.63 inches, and from subirrigation 1.96 inches, the saving being 3.67 inches, or 52.29 per cent of the water applied. While subirrigation has never proven satisfactory, this experiment is interesting, as showing the large saving which might be made if subirrigation could be made practicable.

All the records show that the larger part of the loss occurs in the first few days after irrigation. With the soil mulches put on after the tanks were watered and with subirrigation the moist soil is protected during the first days when evaporation is heavy. This accounts for the high percentages of saving under those two methods.

The experiments which have a direct bearing on present practise in irrigation are those testing the effects of cultivation after irrigation and of applying water in furrows of different depths. As shown above, the saving in a six-day period by cultivation was 6.25 per cent of water applied; and in another experiment where less water was applied the saving in a three-day period was 2.38 per cent of the water applied. In both instances the heaviest losses occurred between the time of applying the water and the time when the soil was dry enough to cultivate. The maximum saving shown by the furrow experiments was 9.23 per cent of the amount applied, the experiment covering ten days. The curves given in figure 3 show that the difference in the losses with mulches of different thickness practically vanishes in ten or twelve days, and it is probable that 9.23 per cent fairly represents the saving which can be made by applying water in deep furrows rather than on the surface.

Another point forcibly brought out by the experiments is the large loss when water is applied in frequent light irrigations. This practise keeps the water always exposed to the conditions causing the largest evaporation. Unless the nature of the soil or of the crops demands such irrigations much water can be saved by irrigating less often.

In one experiment with wheat at Tulare, in which the maximum amount of water applied was 24 inches, the yield increased with the quantity of water. In a second experiment in which the maximum quantity of 27 inches, the maximum yield was secured from the use of 18 inches, the decrease from this maximum due to the use of 27 inches being 50 per cent. These experiments lead to the conclusion that 18 to 24 inches is the best amount of water to apply to wheat under conditions similar to those at Tulare.

In an experiment with barley, also at Tulare, the tanks received 7, 12, 15, 20, and 24 inches. With one exception the yields increase with increased amounts of water. In a second experiment the amounts of water applied were 12, 18, and 27 inches; the maximum yield was secured from the use of 18 inches, and the minimum from the use of 27 inches. The experiments show that barley requires about the same amounts of water as wheat, 18 to 24 inches producing the best results.

In two experiments with horse beans at Berkeley, in which the maximum quantity of water applied was 38 inches, the yields increased as the amount of water applied increased, showing that horse beans can make use of large amounts of water.

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